CSCI 2300 – Software Engineering and Object Oriented Software Design

Instructor: Javier Gamo

Project 3: Optics simulations using JAVA

Deadline: May 2, 23.59H

What to Submit

You should upload your answer into blackboard on a single ZIP file, including **all the files** you use/produce. Be sure the file you submit have exactly the following name:

FirstnameLastname_P3.zip

Example: JohnSmith_P3.zip *for Project 3 submitted by John Smith*

Since this is a team project, you must upload all the common files for the project, and a short presentation of the tasks you have developed on this project, as described below.

Moreover, you will be presenting in class your contribution to the project, during week 17 (most likely by May 3).

Background

A Virtual Remote Laboratory (VRL) is a system where the student can perform experiments from home, using the web. VRLs are becoming popular in many disciplines. They aim to use the web to perform simulated experiments, but also to manage physical experiments remotely. VRLs have several advantages over physical, on-site labs, including:

- Access from multiple geographic locations (e.g. students from different cities, countries, etc.).
- Efficient sharing of resources between schools, resulting in economies of scale.
- Improved quality through specialization (e.g. each center may focus on developing one / several practices, rather than undertake the development of all corresponding to the same subject well).
- Experiments can be done with no risk to the students, in case of failure.

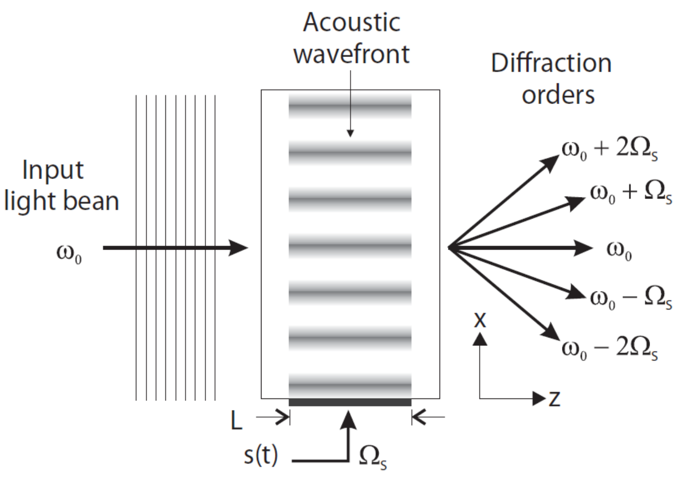
In this project, you will implement a Virtual Lab in Optics, simulating the Acousto-Optics interaction, as explained below.

There are no constrains at all regarding the design and functionally of your project, apart from the minimum requirements mentioned below. This is a team project. All the grading aspects will be shared, except the presentation, which is being graded individually.

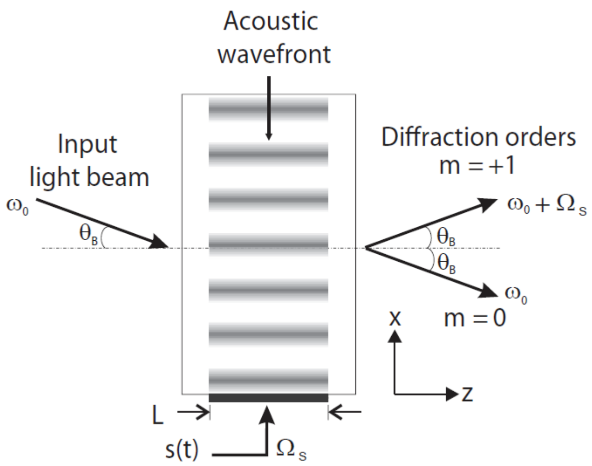
The Acousto-Optics interaction

Acousto-optics describes the interaction of sound with light (AA Opto-Electronic, 2017). A sound wave unleashed on an optical medium (crystal) using a piezo-electric transducer creates a disturbance in the refractive index of the medium. Any incident laser beam will be diffracted by this grating, generally giving a number of diffracted beams, as shown in Figure 1.

The sound can then control a light beam hitting the crystal. This fact, known as Acousto-Optical (AO) effect is used in various devices, such as beam deflectors, optical modulators, filters, isolators and spectrum analyzers, among others.



a) Raman-Nath regime



b) Bragg regime

c)

d)

Figure 1. AO interaction layout under a) Raman-Nath regime and b) Bragg regime. Laser beam output after the AO material on c) Raman-Nath regime and d) Bragg regime

Since optical frequencies are much higher than acoustic frequencies ($10^{15} Hz$ versus $10^{9} Hz$, respectively), the crystal can be considered a static and homogeneous medium. According to the interaction geometry between light and sound, two different AO regimes can be distinguished:

- **Raman-Nath regime.** This effect occurs when light strikes perpendicularly to the direction of propagation of the sound on the glass. Different sidebands are then generated, corresponding to the different diffraction orders ($\mathrm{m} = \pm 1, \pm 2 \ldots$)

- **Bragg regime**. In this interaction geometry, only one diffraction order ($\mathrm{m} = 1$) is generated, along with the unavoidable DC (Direct Current, $\mathrm{m} = 0$) central spot. The diffraction efficiency (e.g. the optical power accumulated on the diffraction order) is then maximized compared to the Raman-Nath regime.

In practice, the Klein and Cook Q parameter (also known as *Quality Factor*) is used to distinguish both AO regimes:

$$Q = \frac{2 \cdot \pi \cdot \lambda_0 \cdot \mathrm{L}}{n \cdot {\Lambda_S}^2} = \frac{2 \cdot \pi \cdot \lambda_0 \cdot \mathrm{L} \cdot {\mathrm{F}_S}^2}{n \cdot {\mathrm{v}_S}^2} \qquad [1]$$

Where

$\lambda_0 = \frac{2\pi}{\omega_0}$ is optical wavelength of the incident laser beam

L is length of the transducer

$\Lambda_S = \frac{2\pi}{\Omega_S}$ is the wavelength of the acoustic wave

F_S is the acoustic frequency

v_S is the acoustic velocity

n is the refraction index of the crystal

When $Q \ll 1$ the interaction corresponds to Raman-Nath regime, and several diffraction orders are produced. On the other hand, the interaction follows the Bragg regime when $Q \gg 1$.

The application of laws of conservation of energy and momentum produce in a simple form the well-known Bragg equation:

$$\sin \theta_B = \frac{\lambda_0}{2 \cdot n \cdot \Lambda_S} = \frac{\lambda_0 \cdot \mathrm{F}_S}{2 \cdot n \cdot \mathrm{v}_S} \qquad [2]$$

Where θ_B is the angle of internal deflection within the crystal (also called the Bragg angle), and the remaining parameters were already described. Since the angles are very small, we can typically use the approximation:

$$\sin \theta \approx \tan \theta \approx \theta \text{ (in radians)} \qquad [3]$$

The external deflection angle (at the exit of the glass) is then:

$$\theta'_B = n \cdot \theta_B \qquad [4]$$

The *diffraction efficiency* (*D.E.*) is a measure of how much optical power is diffracted into a designated direction compared to the power incident onto the diffractive element. Under Bragg regime, the diffraction efficiency can be calculated as:

$$D.E. = \frac{I_1}{I_0} = \sin^2 \frac{\pi}{2} \sqrt{\frac{P}{P_0}} = \sin^2 \sqrt{\frac{\pi^2}{2 \cdot {\lambda_0}^2} M_2 \frac{L}{H} P} \qquad [5]$$

Where

I_0 is the maximum intensity of the incident optical beam

I_1 is the light intensity on the first diffraction order (m = 1)

P is the acoustic power

M_2 is the acousto-optic *figure of merit* for the crystal

H is the height of the acoustic beam

L is the length of the acoustic beam

λ_0 is the optical wavelength of the incident laser beam

Material	Type	Optimum optical range for AO application (nm)	Incident optical polarization (*)	Refractive index	@ λ (nm)	Max CW laser power density (W/mm^2)	Acoutic velocity (m/s)	M_2 AO figure of merite ($10^{-15} S^3/kg$)	@ λ (nm)
Ge	Crystal	2500 - 11000	Linear//	4	10600	5	5500	180	10600
Doped Glass	Glass	500 - 650	Unpolarized	2.09	633	1	3400	24	633
$Ge_{33}AS_{12}Se_{55}$	Glass	1100 - 1700	Unpolarized	2.59	1064	1	2520	248	1064
As_2S_3	Glass	700-900	Unpolarized	2.46	1150	1	2600	433	633
$PbMoO_4$	Crystal	450 - 1100	Unpolarized	2.26/2.38	633	0.5	3630	36	633
TeO_2	Crystal	450 - 1100	Linear ⊥	2.26	633	5	4200	34	633
TeO_2	Crystal	350 - 4500	Linear-Circular	2.26	633	5	620	1200	633
SiO_2 (fused silica)	Glass	200 - 200	Linear ⊥	1.46	633	> 100	5960	1.5	633
SiO_2 (fused silica)	Glass	200 - 200	Unpolarized	1.46	633	> 100	3760	0.5	633

(*) : // and ⊥ means parallel and perpendicular to the acoustic wave direction for optimum AO coupling

Table 1. Main characteristics of the most used AO materials

Requirements

<u>Graphic User Interface (GUI)</u> (**60 points**): Design a GUI for your program. You have all the freedom when designing your GUI, but at least it should have the following sections:

- **Theory**: Physics principles behind AO interaction should be described, as a way to introduce the user to these optical phenomena. Figure 2 shows an example of this module. **You do not have to replicate this GUI literally**; just get it as inspiration for your own theory module.

Figure 2. Example of theory module for your GUI

- **Simulation**: The simulation of the AO interaction will be carried out using a GUI similar to the one displayed on Figure 3. **Please note these examples are not fully developed.** Just use them as inspiration to build your own GUI.

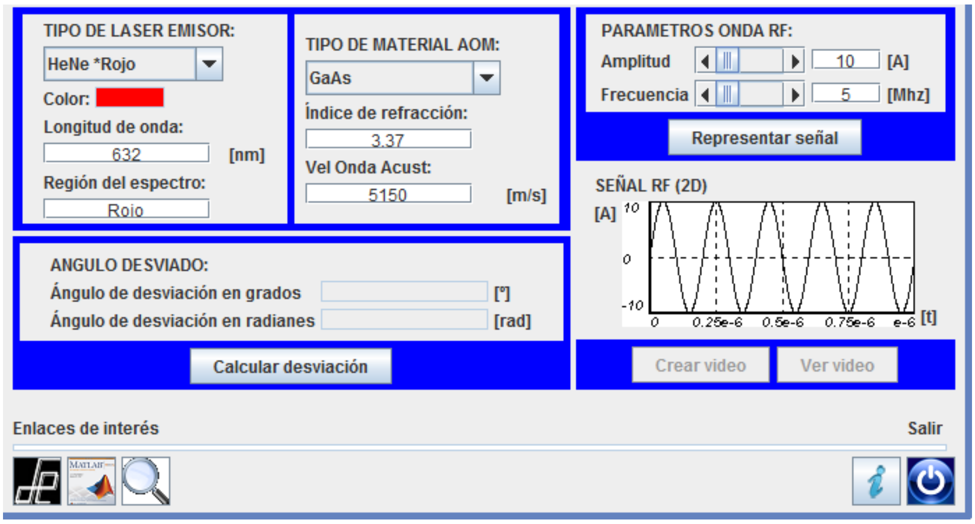


Figure 3. Example of AO simulation experiments

- The user can select an AO material using a combo list. Once the AO material is selected, the GUI should display the following parameters:
  - *Optimum optical range for AO applications (nm)*: The user then selects a particular wavelength from the range of possible values for the selected AO material, as shown on Table 1. If the wavelength is included in the visible range (400 – 700 nm), the corresponding color of that wavelength should be also displayed using the Class Color
  - *Incident optical polarization*: note that some materials (e.g. SiO_2) can work under different polarization modes, as shown on Table 1. In that case, your GUI should display a combo box to select the desired polarization mode.
  - *Refractive index*: use the value provided on Table 1 for any incident wavelength.
  - *Acoustic velocity (m/s)*: as defined for the selected AO material on Table 1.
  - *M_2 figure of merit* ($10^{-15}\ s^3/kg$): again, use the value provided on Table 1 for any incident wavelength.
  - *L and H:* range 0 – 10 mm for both parameters.
  - *RF signal*: your GUI should represent graphically the Radio-Frecuency (RF) signal. Use Figure 4 as inspiration for this representation. Your graph should change dynamically according to the input parameters:
    - *V (Voltage in Volts)*: root-mean-squared (rms) voltage of the RF wave. Your GUI should ask the user to enter the DC Voltage V_m (range 0 – 24 V) and calculate the corresponding V_{rms} value:

$$V_{rms} = \frac{V_m}{\sqrt{2}} \qquad [6]$$

    - *Fs* (*frequency of the RF wave*): Range from 1 to 1000 MHz

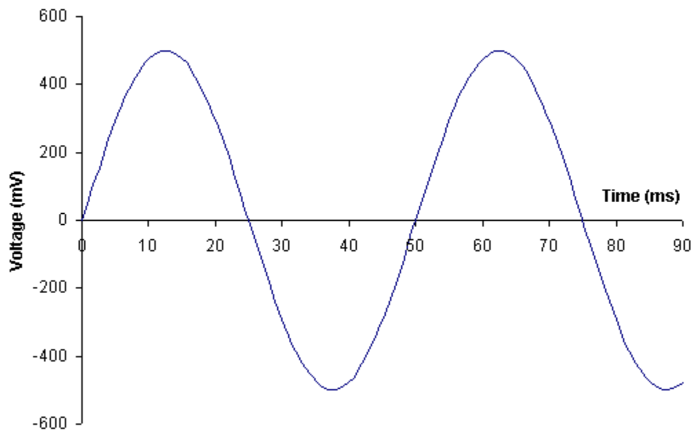


Figure 4. Example of RF waveform signal

- *P (Power in Watts)*: you must set on your GUI the RF Power of your signal between 1 and 2 W (not to destroy the AO device), and calculate and display numerically the corresponding current I_{rms} of your driver RF circuit, using Ohm's Law for AC circuits:

$$P = \frac{V_m \cdot I_m}{2} = \frac{V_m}{\sqrt{2}} \cdot \frac{I_m}{\sqrt{2}} = V_{rms} \cdot I_{rms} \qquad [7]$$

- With all these input parameters, your program should:
  - Represent graphically and numerically (e.g. V_{rms}, $I_{rms}, F_S, P\ldots$), the RF waveform generated with your input parameters, as described above.
  - Calculate and display the Q factor as indicated by Equation [1]. Show on the screen if the experiment is following the Raman-Nath or the Bragg regime, based on the value of Q.
  - If the experiment is following the Bragg regime, calculate and display the diffraction angle (internal and external) as indicated by Equations [2] and [4]. Express your results both in radians and degrees.
  - Calculate and display the Diffraction Efficiency, as shown in Equation [5].
- When entering any parameter on your GUI, you should allow the user to either type them numerically (e.g. "632" for the wavelength of a red laser, expressed in nanometer), or select them using a graphical object (e.g. combo-box with pre-defined values for laser wavelegths, as in Figure 3. Example of AO simulation experiments
- **Both methods should be available on your GUI.**
- Your code should **check for errors** when entering parameters (e.g. don't allow entering negative values for the wavelength, RF frequency, etc.).
- Use JavaFX to include a simple representation of the AO interaction. Figure 5 shows an example. Again, you can use this as an inspiration for your own representation of the AO interaction. **Your representation should change dynamically with the input parameters** (e.g. laser color, changes in the Bragg angle, etc. should be reflected in the layout).

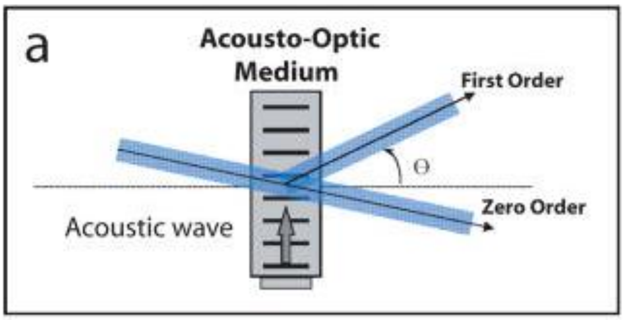


Figure 5. AO interaction layout

- Use the Class Math for the common trigonometric functions. See also the **reference** section below for other numerical methods in case you need them.
- Build a graphical, top-view representation of your diffraction experiment (see Figure 5). This top-view layout should be dynamically adjusted when changing your parameters (e.g. if you switch your laser from red to green, your layout should show your beam lights in green; similarly, if the diffraction angle is augmented, this increment should be also reflected in your layout, etc.).
- Include an "ABOUT" section with your credits (team names, date of creation, version number, contact info, etc.)
- **EXTRA BONUS (10 points)**:
  - Allow importing your input parameters from a text (`INPUT.TXT`) file, and exporting you output results (Bragg angle, Q parameter, Diffraction Efficiency) on another text (`OUTPUT.TXT`) file.
  - Allow to save the layout layout representation as a graphic (`LAYOUT.PNG`) file, and send it to a printer.

UML and Javadoc Report (20 points): You must include a report (DOC or PDF file) describing your project. In the report, you must represent your classes, with their *data fields* (e.g. properties) and *behaviour* (e.g. methods) using UML diagrams. **Also, your code should be extensively commented. You must also provide the HTML documentation produced by Javadoc.**

Presentation & delivery (**20 points**): You must deliver:

- Your **source code**, preferably using Eclipse.
- An **executable (.JAR)** file of your final project. See for instance: https://www.youtube.com/watch?v=mE3rbtKm-pk
- A **presentation** (PPT or PDF file), describing the tasks you have performed in the project. **You will be giving this presentation in class** with your team-mates. A professional, good-quality presentation of your project will count!

Assessment

This assignment contributes 15% of your final course grade. The maximum possible grade on this assignment is 100 points.

References

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