Technical University of Moldova
Faculty of Computers, Informatics and Microelectronics
Department of Software Engineering and Automatics
Department of Physics

# Study of free oscillations in the electromagnetic field

**Semester**: II

**Chapter**: I

**ECTS**: 10

**Graded: Tronciu Vasile**

**Team number**: I

**Chisinau, 2020**

# Team members

Data analyzer and Resource Investigator, Coder in Matlab

**Boico Alexandr**

In my position as data analyzer and resource investigator, my task was to structurise all the information about electromagnetic oscillations in one file, which consisted of many important aspects. The second important task I had was to make a list of needed formulas and to implement them in Matlab. Last, but not the least, an important aspect of my work was to consult Nicolae on issues related to my previous roles and to submit ideas and advice on the implementation of the several functions and on design of the app. Generally, I made sure that all my colleagues gain a full understanding of the project's topic and aim.

I have transcribed the most important formulas into MatLab code that was used by Nicolae as a guide for the Java application he has developed. The entire process of making the app was closely supervised by me. At the end, I tested the application and made sure no misinformation is delivered to the users.

Developer of the app
**Basso Nicolae**

Being the developer of the project application, I was deeply rooted in understanding the aims and the needs of our project. Collaborating with Alexandr made it possible for me to think over the structure and “embody” the solution for the goal our project: my programming skills and some knowledge in physics, combined with Alexandr’s deep analysis of the problem on the science language resulted in successful determination of properties damping electromagnetic oscillations possess.

By the end of the project, I have completed developing an application aimed at students and junior researchers in the field of electromagnetic waves, in particular, and electromagnetism, as a whole. Following Alexandr’s instructions, I provided features like “interactivity”, “graphic representation of data” and “formulas display” to my application. I hope it will help users in their pursuit of electromagnetism research, offering them a headstart in data processing and analysis, as well as some real-time simulations and predicament.

<u>Report Co-editor</u>
**Corman Daniel**

My task during this report was to collaborate with Anastasia in order to organize the information and structure the report. It was an interesting experience as it was much easier to work with someone, not by my own, thing that generated a lot of interesting ideas that provided the result we have today. It was a fructuous collaboration because the atmosphere in the team was friendly, and everyone has done their part of the task in time.

Generally, I have collected relevant data, pictures and information from what my teammates uploaded and included it in the report, describing each step taken. Organizing and filtering information along the way is crucial in a project, for several people are working on the same topic, and the huge amount of data can be overwhelming sometimes.

Team Leader, Report Editor & Logistics

**Gavrilita Anastasia**

My role throughout the project was to organize the team and establish an effective two-way communication between the team and our mentor in the most effective way. Each of the team's members have a specific field in which they excel. I help them connect as a team.

For instance, Nicolae is good at programming in Java. He managed to put projects together in the most effective time. Meanwhile, Alexandr knew lots of things about our project topic and he was passionate about experimenting with electromagnetism. Being the team mediator, I helped Alexandr's wonderful ideas transfer into Nicolae's code. Following their work, Daniel and I would constantly transcribe and describe everything in the report.

Another thing I took care of was the team meetings. I wrote down notes during our discussions, after which I would proceed to plan our work for the following period of time, based on the meeting notes. I guided my teammates throughout the working process, telling each member whenever it was the time for them to step in or when a specific task was due. The meeting notes helped us identify the project's main building blocks and put them together.

Collaborating with Daniel on the report was also part of my duties, for I was in charge of seeing the general picture of the project. My main task was to ensure a smooth transition between the theoretical and the practical ideas reported and take care of the outline of the report as a whole. What's more, I included the members' work, already "translated" in a format that helped the new information blend in with the already existing one.

# Abstract

Throughout the project, we tried to think of an easy, yet elaborate application to address various students that want to simulate a laboratory on the electromagnetic waves wherever they want, even outside the class. Therefore, we created an application with GUI that will provide the user a pleasant interaction during the computer assisted experiment and the data the user will receive will be the actual outcome of the fizic experiment. Our team thinks that the future will go side by side with computer technologies and with usement of these technologies for analytic purposes. That's why it is crucial to develop a way to do experiments using computer programs, because it's less expensive than a real physical experiment and it allows the specialists to deal with a huge amount of data and analyze data a way faster, without loss of important information that could spoil the objective analyze of the information from outcome and making the wrong conclusions. The previous experience shows computer assisted experiments represent for scientists a very important tool in analyzing information at a high level, and in making simulations that are quite similar to the real physical processes. Making simulations can help us to better understand a lot of physical behaviors of different processes without involving a lot of resources for the actual physical experiment to take place.

In the context of the 2020 quarantine, we came up with the idea of this software for all students that take Physics courses. They will be able to do all the laboratory work in a safe way. What's more, this software is also useful for students that weren't able to come to classes on a laboratory day. They will still be present and active in class.

The Behaviour of the electromagnetic waves is described by the the following features amplitude and frequency, as it is shown in Figure 1.

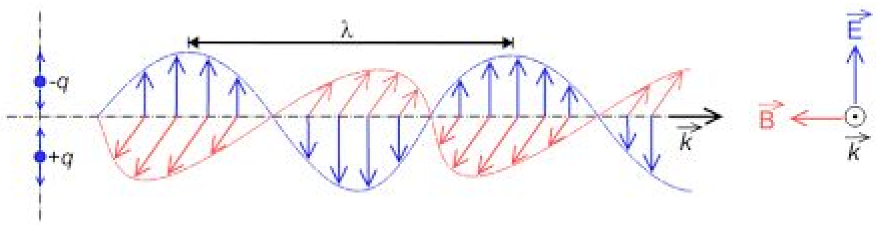


**Figure 1. Electromagnetic waves behaviour**

During the experiment there are errors that will occur for sure, errors that we must take in account when we analyze the outcome of the experiment. The frequency of error ocurement is described by Gauss "Bell" function described graphically in Figure 2.

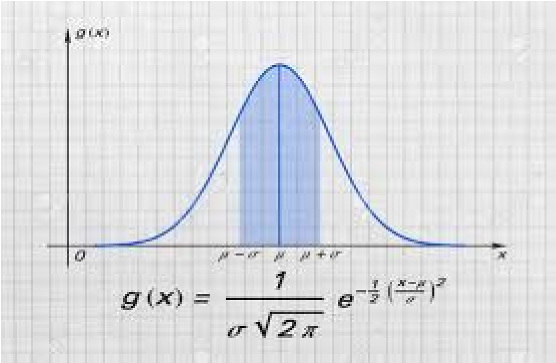


**Figure 2. The Gauss "Bell" function for error occurement**

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# Introduction

The oscillation of a body or a system with its own natural frequency, without involving external forces that can cause motion, are called free oscillations or natural oscillations. Those oscillations are most commonly related to electromagnetic oscillations that have a huge rate of usement in electromagnetics. Moreover, the concepts and techniques developed can be applied, with minimum adaptations, to a host of situations. One of the most important applications for linear oscillations are present in electrical circuits. The natural frequency depends on the "force constant" k restraining the motion: k would be larger for a double bond than a single bond, and larger for stretching than for bending.

The simplest mechanical oscillating system is a weight attached to a linear spring subject to only weight and tension. Such a system may be approximated on an air table or ice surface. The system is in an equilibrium state when the spring is static. If the system is displaced from the equilibrium, there is a net restoring force on the mass, tending to bring it back to equilibrium. However, in moving the mass back to the equilibrium position, it has acquired momentum which keeps it moving beyond that position, establishing a new restoring force in the opposite sense. If a constant force such as gravity is added to the system, the point of equilibrium is shifted. The time taken for an oscillation to occur is often referred to as the oscillatory period.

Alternating current is an electric current which periodically reverses direction, in contrast to direct current which flows only in one direction. Alternating current is the form in which electric power is delivered to businesses and residences, and it is the form of electrical energy that consumers typically use when they plug kitchen appliances, televisions, fans and electric lamps into a wall socket. A common source of DC power is a battery cell in a flashlight. The abbreviations AC and DC are often used to mean simply alternating and direct, as when they modify current or voltage.

# Back-up Theory

In a folder named "Useful materials & data", we gathered all the early data to be analyzed and used further on. An example has been added below (Figure 4).

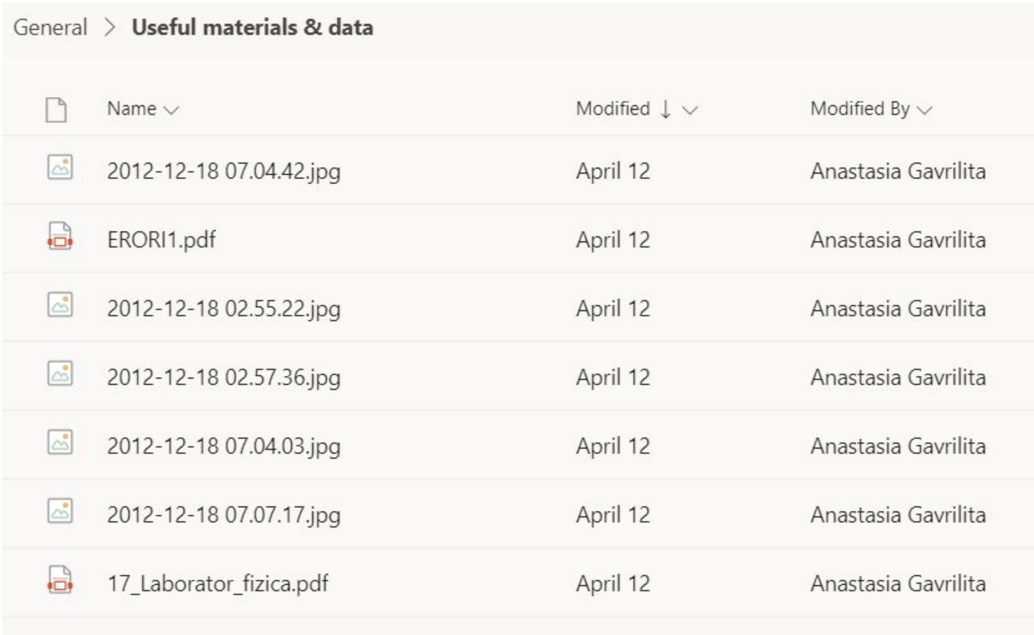



**Figure 4. Putting ideas together**

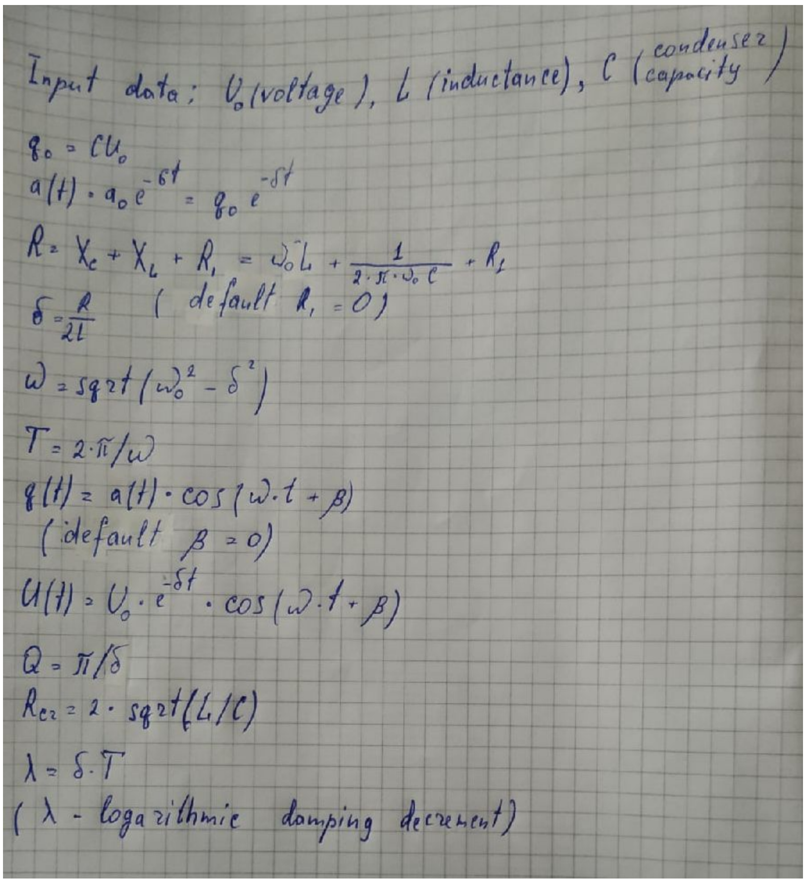



**Figure 5. Example - Formulas discussed during one of our meetings**

# Free oscillations

Free oscillations are movements made by the oscillatory system, which after a short external influence is left to itself. In this case, periodic transitions of one type of energy to another occur, that is, potential energy (energy determined by the position of the system) passes into kinetic energy (energy of motion) and vice versa. If the sum of these energies is preserved during the oscillations, then the oscillations will be undamped, and the whole system - canned. If the energy of the system decreases, then damped oscillations occur, and the system is called non-conserved.

The simplest oscillatory system in mechanics is a load suspended on a spring, moving without friction. In this case, the mass of the spring is neglected and it is believed that all the elasticity is concentrated in the spring. It is known from mechanics that a load unbalanced performs harmonic oscillations, in which a change in position changes with time according to a sinusoidal law.

Similar processes occur during electromagnetic oscillations. The simplest electrical oscillating circuit consists of interconnected inductors and capacitors.

If the capacitor is shorted to the inductor, as shown in Figure 6, it will begin to discharge, and its electric field will begin to decrease, but at the same time, the electric current of the capacitor discharge will appear in the circuit, which causes a magnetic field to form in the inductor. After a time equal to a quarter of the oscillation period, the capacitor is completely discharged, the energy of its electric field becomes equal to 0, but the magnetic field, in turn, reaches its maximum, and, therefore, the energy of the electric field transferred to the energy of the magnetic field. Further, the magnetic field will disappear, since there are no currents supporting it, which will cause an excess of self-induction, which, in accordance with the law of Lenz, will tend to maintain the discharge current of the capacitor, therefore, the capacitor will be recharged and an electric field of the opposite direction relative to the initial one will appear between its plates. In the future, the capacitor will again be discharged and a current will appear in the circuit, directed opposite to the current in the previous stage of the process. At intervals equal to the full period of oscillation, the electrical state of the circuit will be the same as at the beginning of the oscillation.

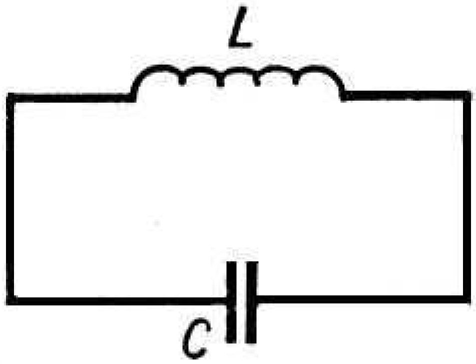



**Figure 6.**

If the loop resistance is zero, then the indicated process of periodic transition of electric energy into magnetic energy and vice versa will continue indefinitely, and we will obtain undamped oscillations (Figure 7a). In reality, the resistance is always non-zero. As a result, the energy originally stored in the circuit is continuously consumed in the generation of Joule-Lenz heat, so that the intensity of the oscillations gradually decreases, and after some time the oscillations cease altogether. Therefore, on the oscilloscope screen we see a type B curve Figure 7. If the loop resistance is increased, then the oscillation attenuation will also increase (Figure 7c).

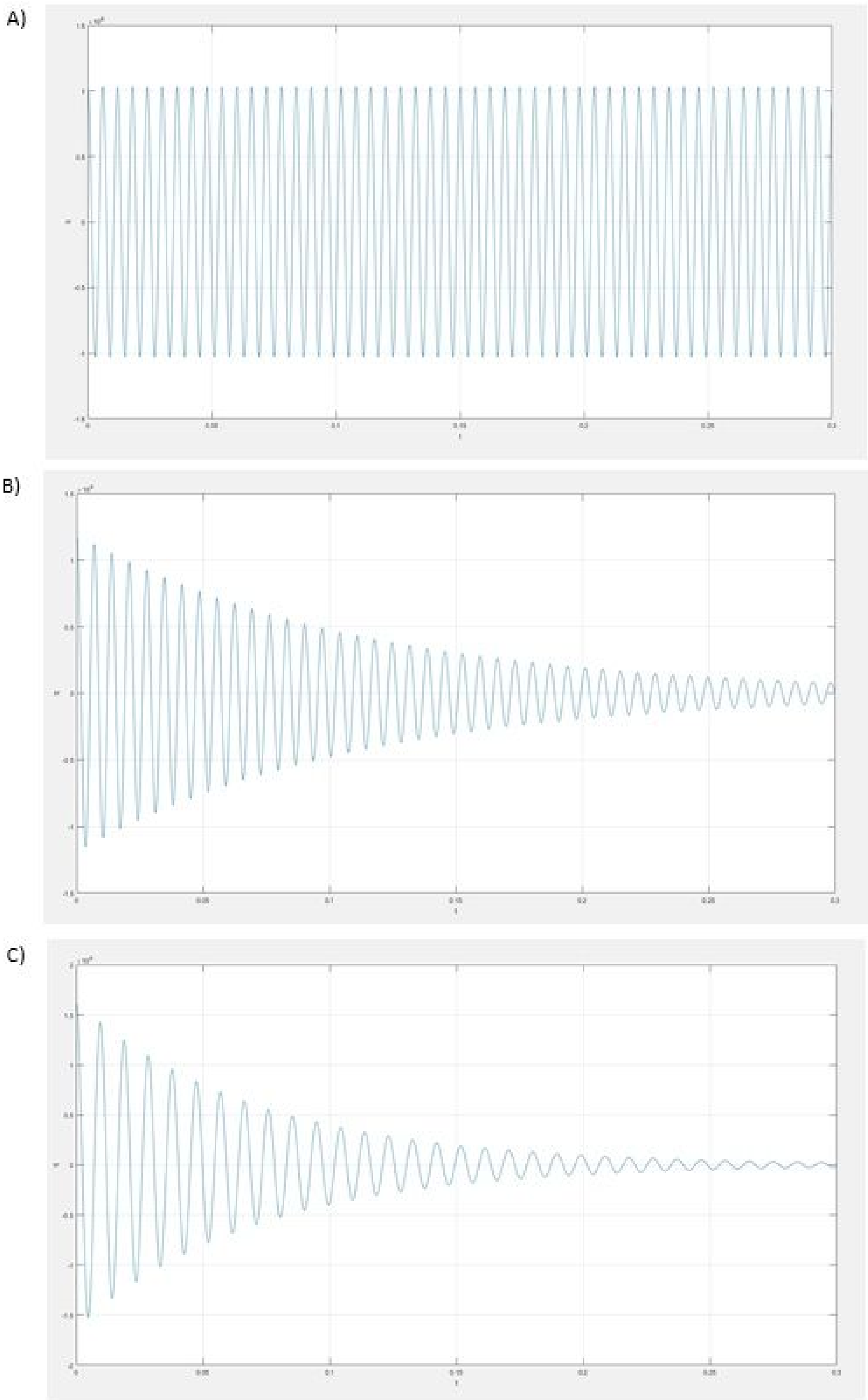


**Figure 7.**

# Fluctuations in the presence of attenuation

Consider a real circuit whose resistance is not equal to zero (Figure 8).

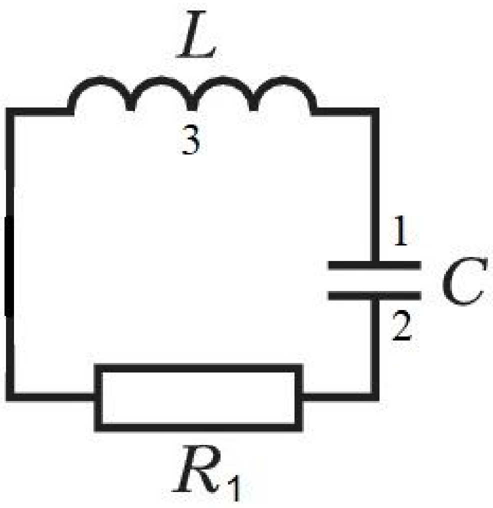



**Figure 8.**

To find the equation of oscillations in the circuit, we use Ohm's law for a section of the circuit 1-3-2:

$$IR = (\varphi_1 - \varphi_2) + \varepsilon_{12}, \tag{1}$$

where $\varepsilon_{12} = \varepsilon_s$.

Expressing current in (1) $I$, potential difference $(\varphi_1 - \varphi_2)$ and EMF of self-induction through the charge of the capacitor q and the loop parameter, we obtain the differential equation of the damped oscillations in the loop. $\varepsilon_s$

$$L\frac{d^2q}{dt^2} + R\frac{dq}{dt} + \frac{q}{C} = 0, \tag{2}$$

Introducing the attenuation coefficient

$$\delta = \frac{R}{2L}, \tag{3}$$

where R is the loop resistance and is equal to

$$R = X_C + X_L + R_1, \tag{4}$$

we proceed to establish where the natural frequency of the circuitous. In other words, we look for the frequency of free undamped oscillations, with no energy loss (at R = 0). Subsequently, equation (2) can be transformed as follows: $\frac{1}{LC} = \omega_0^2$

$$\frac{d^2q}{dt^2} + 2\delta\frac{dq}{dt} + \omega_0^2 q = 0, \tag{5}$$

If the attenuation is small, $\delta^2 < \omega_0^2$, then the solution for equation (5) is

$$q = a_0 e^{-\delta t} cos\,(\omega t + \alpha), \tag{6}$$

where $\omega = \sqrt{\omega_0^2 - \delta^2}$ (6) is the frequency of the damped oscillations in the circuit. Thus, when a charged capacitor is shorted to a circuit of series-connected L and $R_1$, the charge on the capacitor plates changes over time according to expression (6).

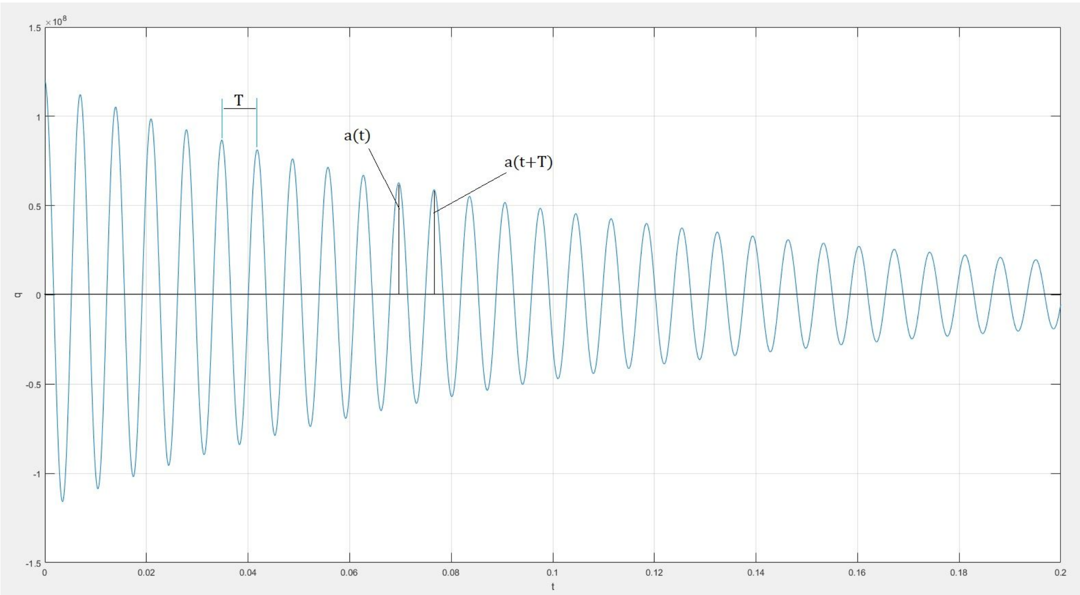



**Figure 9.**

In essence, damped oscillations are not a periodic process ( Figure 9 ), since a quantity that changes with time, for example, a charge, does not take the same value after a period of time equal to the oscillation period, which is calculated by the formula: $T$

$$T = \frac{2\pi}{\sqrt{\omega_0^2 - \delta^2}} = \frac{2\pi}{\sqrt{\frac{1}{LC} - \frac{R^2}{4L^2}}} \tag{7}$$

Nevertheless, if the damping is small, then damped oscillations can be said to be periodic, the amplitude of which, where, gradually decreases according to the law (Figure 7B).

$$a\,(t) = a_0 e^{-\delta t} = q_0 e^{-\delta t} \tag{8}$$

The voltage across the capacitor $U_c$, the amperage in the circuit $I$, the voltage across the inductor in the same way as the charge makes damped oscillations, since they are associated with the charge.

$$U_c = \frac{q}{C} \;; I = \frac{dq}{dt} \;;\; U_L = IX_L \tag{9}$$

To quantify the attenuation, a logarithmic attenuation decrement is introduced:

$$\lambda = en\frac{a(t)}{a(t+T)} = \delta T = \pi\frac{R}{\omega L} \tag{10}$$

With increasing loop resistance, the damping coefficient increases, the oscillation frequency decreases, and the period of damped oscillations increases. At a certain value of resistance, the period becomes equal to infinity, and the frequency is 0. In this case, an aperiodic discharge of the capacitor occurs instead of oscillations (Figure 10).

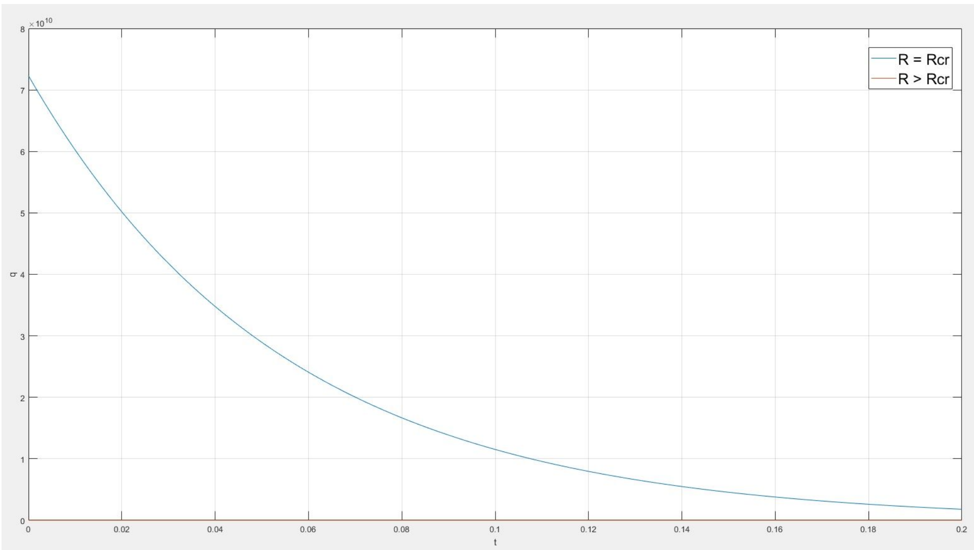



**Figure 10**

This resistance value is called critical and equals.

$$R_{crit} = 2\sqrt{\frac{C}{L}} \tag{11}$$

To determine the quality of the circuit as an oscillatory system, a parameter is used - the quality factor of the circuit, calculated by the formula:

$$Q = \frac{\pi}{L} = \frac{\omega L}{R} \tag{12}$$

From the formulas above, we conclude that the following conditions must be satisfied for the oscillations to occur: $\omega_0^2 > \delta^2$ and $R < R_{crit}$.

# Implementation in Matlab

After analyzing the sources, we got a list of formulas( Figure 2), which we implement almost unchanged in the Matlab programming language.

For us, Matlab was a sandbox where we can test different functions. For example, Matlab-program shows graphs of time dependence not only on the charge ( Figure 11A) (as in the final version of the app), but also on the voltage ( Figure 11B) and amplitude ( Figure 11C).

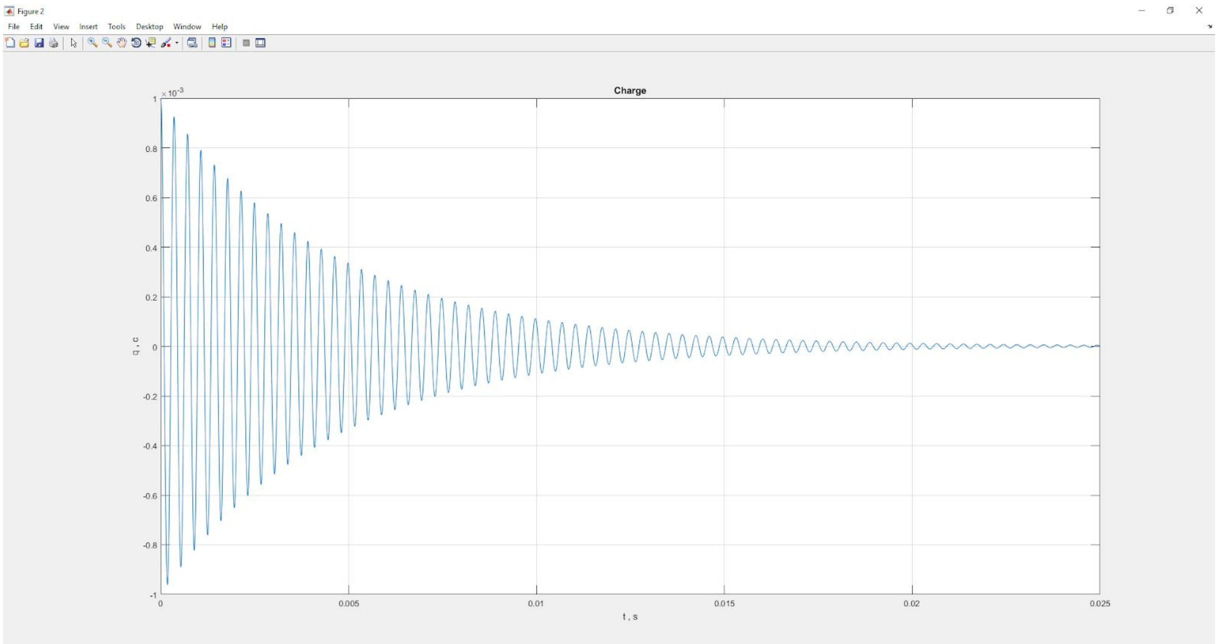



**Figure 11A**

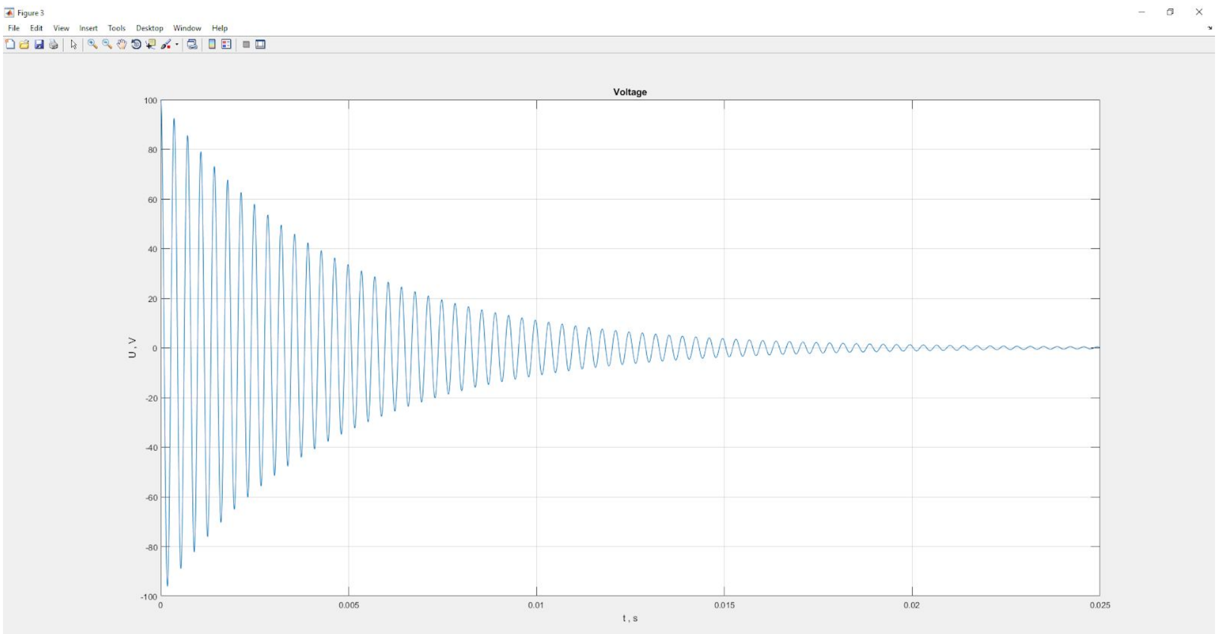



**Figure 11B**

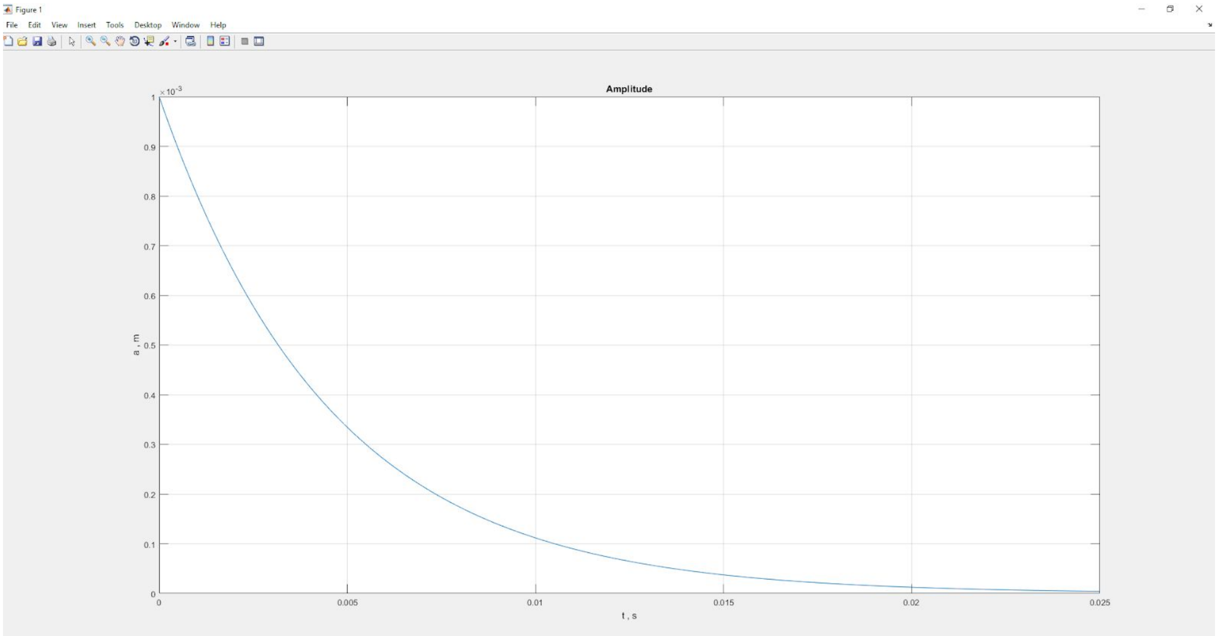


Figure 1
File Edit View Insert Tools Desktop Window Help
Amplitude
×10⁻³
a , m
t , s
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0.005
0.01
0.015
0.02
0.025

**Figure 11C**

# Measurement of physical values

Physics is a science that studies phenomena. The physical theories must have hypothetical background and must be based on conclusions that can be proved or disproved through experimental way.

Therefore, a physical experiment is nothing but a measurement. And of course there are errors that could occur during the measurements while a physical experiment is taking place.

The general equation describing the measuring process is described by the formula:

**Physical measure = Value * Unit**

Changing the unit of measurement will change the outcome value of the experiment, as well.

## Error classification

There are several types of errors:

1.Measurement errors : $\delta A = a - A$;

2.Accidental errors: $\delta A_i = a_i - A$;

The accidental type of errors have a small impact on the outcome of the experiment

The occurement of the errors is described by the : Gauss Bell:

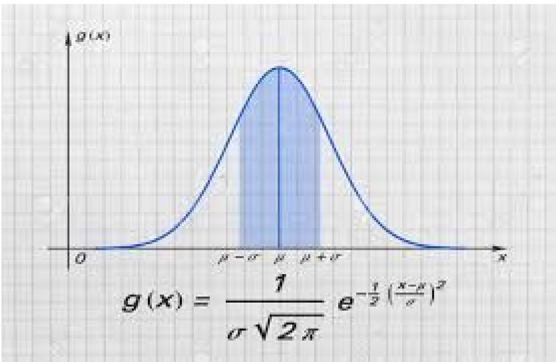



**Figure 11. The Gauss "Bell" function of error occurrence**

The form of the Gauss function (Figure 11)and this dependence lead us to the conclusion that making the number (n) of measurements, and computing the arithmetical average of this values we'll get the value that is most close to the real value, so the accidental error of arithmetical average is described by the formula: $\delta a_i = a_i - a$.

Statistically it could be computed, for the string of found values a minimal interval that can express with the maximal probability the real value of the measurements:

$A \in [a - \sigma a, a + \sigma a]$ -- where $\sigma$ is the actual error.

For a better determination the statistical theory implies a larger number of determinations in order to reduce the error and to get the most close result to the actual value.

There are also systematic errors which have the same direction (the same sign), having a well defined value, that could be constant or variable.

The gross errors occur when we are making only a few observation experiments. If in this string of determinations there is at least one value that differs a lot from the others we must not take it into consideration and to repeat the experiment, as it's outcome has been deteriorated because of out of range determination.

Reading errors are a special class of errors related to direct measurement, and are unique for a particular value. In case we are working with an non-professional measuring device which has a low degree of precision, we will get an error described by the formula:

$\Delta a$ = (value of measurement scale / 100) * C;

For a better precision of the experiment we have to compute the relative error:

E = ($\Delta A$ / a); - relative error;

Samples of computations:

# Problem (Aims)

Our team aims to create a software that assists students in conducting physical experiments in the field of electromagnetism. This shall help them gain a better understanding of the concept of electromagnetism and electromagnetic waves.

The software is mainly aimed at students that don't have the possibility to physically attend classes: students with disabilities, those with remote learning programs, as well as students in quarantine.

**Features:** Firstly, our software will provide the user with a GUI interface for data visualisation. Students will be able to build virtual electric circuits and simulate the current transfer by modifying the voltage, resistance, intensity, the number of capacitors, resistors, switches (Figure 12) etc. Figures 14.1-14.6, show the way a user can interact with GUI imputing the data for the experiment, and watching the outcome (Figure 14.4). The soft will interactively display the circuit that was built, as well as some data results and the calculations behind them.

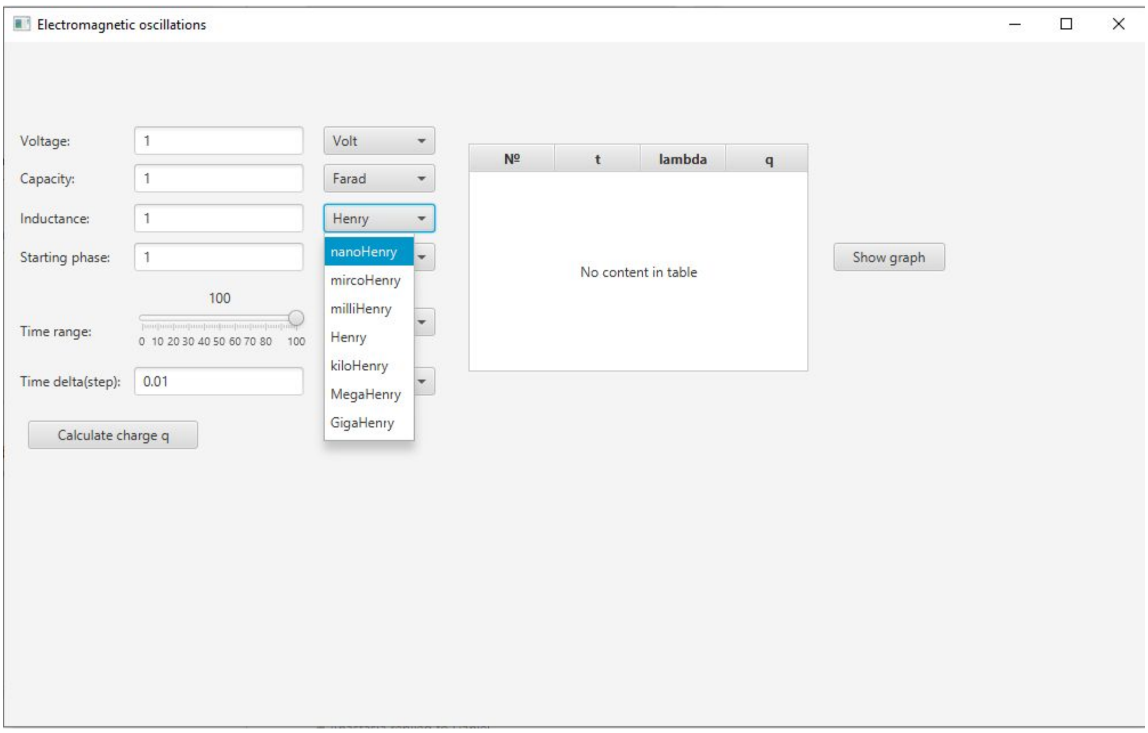



**Figure 12. Early GUI sample**

**The example of the circuit can be described graphically as it is shown in Figure 12.**

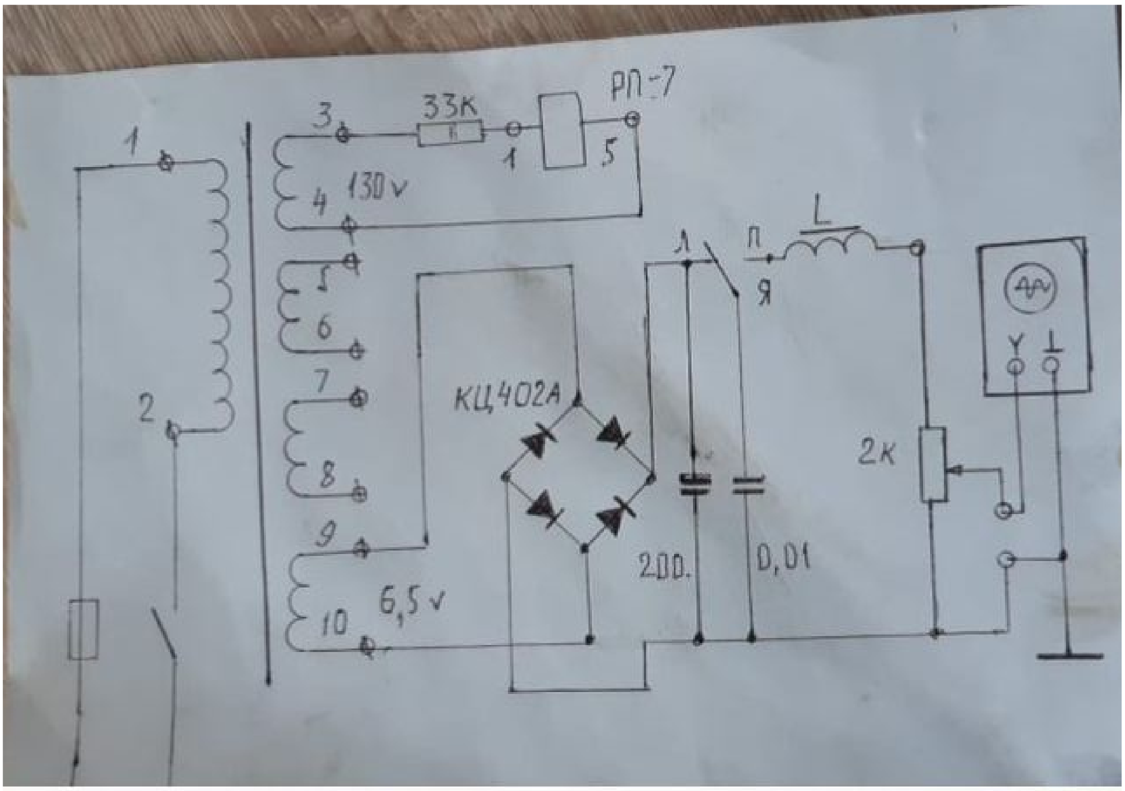



**Figure 13. Graphic representation of the circuit model we want to simulate**

# Key-Features of our app:

- **Real-time decision making and data analysis**
- **Error monitoring, recovery and control**
- **Provides full audit trails and detailed error logging**
- **Instrument pooling (electric circuits controlled by several machines)**
- **Instrument hot-swapping in virtual simulations**
- **Ability to simulate and time a process run**
- **Manual operation steps can be added to the workflow**
- **Ability to unify multiple islands of automation treating them as part of a larger connected system**
- **Graphic representations of circuits**
- **Simple interface, meant to help the user focus on the interaction with the prompt window**

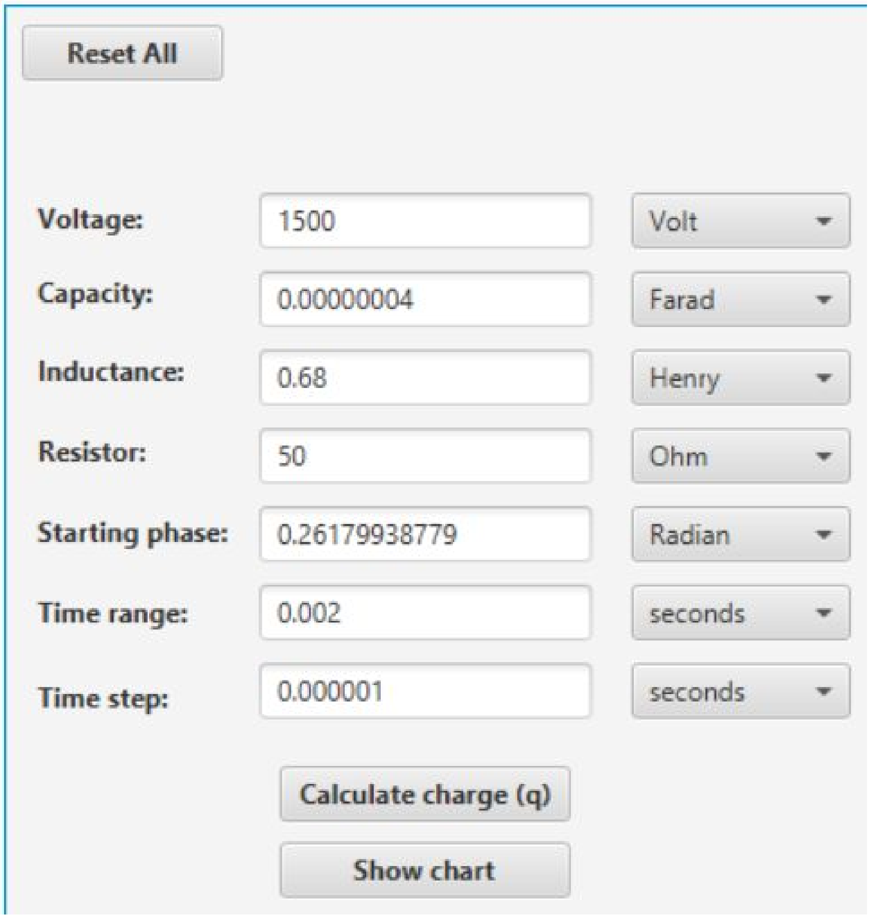



**Figure 14.1. Data input**

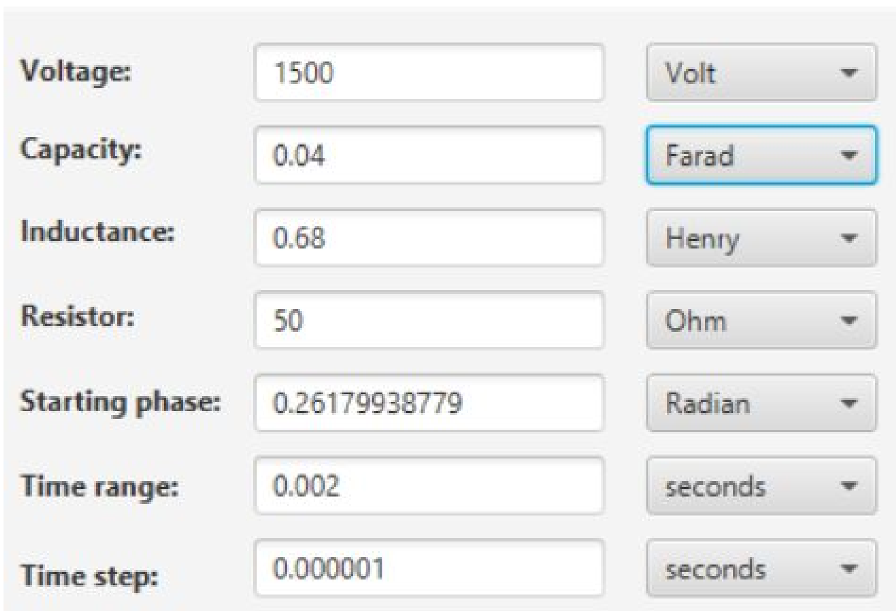



**Figure 14.2. Data input**

| № | t (s) | q (C) | A (m) | Vc (V) |
|---|---|---|---|---|
| 1 | 0.0 | -4.5581274751075484E-5 | 360186.79700... | -1139.53186 |
| 2 | 1.0E-6 | -5.4898489219260326E-5 | 359083.27214... | -1372.46223 |
| 3 | 2.0E-6 | -5.928102628704981E-5 | 357983.12821... | -1482.02565 |
| 4 | 3.0E-6 | -5.836969309415801E-5 | 356886.35486... | -1459.24232 |
| 5 | 4.0E-6 | -5.227784921779439E-5 | 355792.94175... | -1306.94623 |
| 6 | 4.999999... | -4.157844365637999E-5 | 354702.87860... | -1039.46109 |
| 7 | 5.999999... | -2.7250297082051395E-5 | 353616.15514... | -681.257427 |
| 8 | 6.999999... | -1.058865147042065E-5 | 352532.76113... | -264.716286 |
| 9 | 8.0E-6 | 6.91184670358604E-6 | 351452.68637... | 172.7961675 |
| 10 | 9.0E-6 | 2.369116422788243E-5 | 350375.92071... | 592.2791056 |

**Figure 14.3. Setting the constants & variables that describe the waves behavior**

| | |
|---|---|
| **Initial Voltage:** | 1500.0 (Volt) |
| **Total Resistance:** | 4173.10562561762 (Ohm) |
| **Capacity:** | 4.0E-8 (Farad) |
| **Inductance:** | 0.68 (Henry) |
| **Circuit resistance:** | 4173.10562561762 (Ohm) |
| **T:** | 0.0012014538304512682 (s) |
| **ω:** | 5229.651899998197 (Hz) |
| **λ:** | 3068.4600188365157 |

**Figure 14.3.**

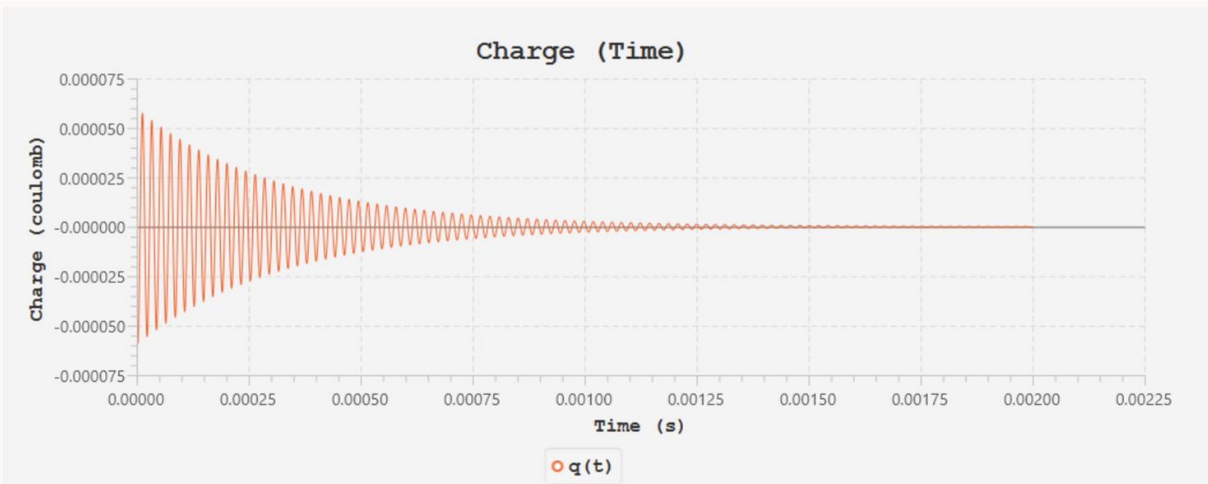



**Figure 14.4, 14.5. Distribution of electric charge waves in time**

**Interface - the process shows the distribution of the charge waves in dependence of time variable**

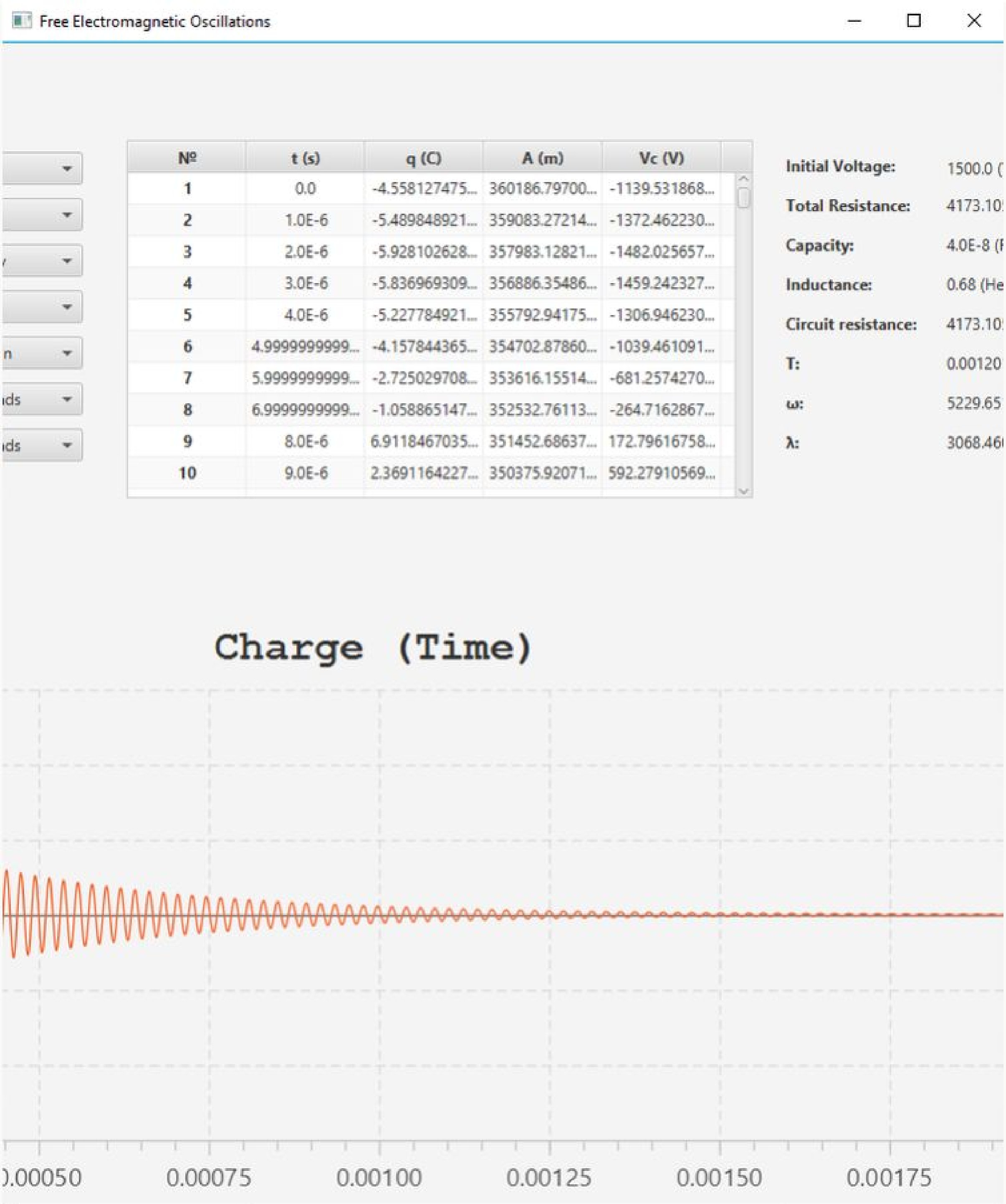



**Figure 14.6. GUI**

**For the GUI shown above, some of the CSS properties have been described and shown in Figure below (14.7).**

```css
/*
    here are CSS properties which were applied in program
*/

.chart-series-line {
    -fx-stroke-width: 1px;
}

.chart-set-font {
    -fx-font-size: 17px;
    -fx-font-weight: bold;
    -fx-font-family: "Courier New";
}

.fx-font-column1 {
    -fx-font-weight: bold;
    -fx-alignment: center;
}

.fx-font-columns {
    -fx-alignment: center;
}
```

**(5)**

**Figure 14.7. CSS properties**

# Research planning

We discussed several ways we could implement the theoretical part into the experimentation stage. The suggestions that stood out were: using packages for data analysis in Python/Java/Matlab, looking at the results of already-implemented solutions in the field. The following sections present our workflow.

## Early samples

The team members have each conducted research on the topic. Alexandr, our data analyzer, provided some early calculations samples which aim to represent data in a user-friendly way.

Together with our mentor, he gathered the necessary information to be comprehended and used in our further project. This information was placed in files for the team, and this files are shown in Figure 15.

| | | |
|---|---|---|
| GitHub Project reference.docx | May 13 | Corman Daniel |
| Electromagnetic oscillations v1.0.mp4 | May 13 | Basso Nicolae |
| link - uri.docx | May 12 | Basso Nicolae |
| schema_1.jpg | April 27 | Tronciu Vasile |
| schema_1a.jpg | April 27 | Tronciu Vasile |
| CSS-styles.png | April 21 | Basso Nicolae |
| updated.png | April 21 | Basso Nicolae |
| Graphics.jpg | March 29 | Basso Nicolae |
| Electromagnetic oscillations template.mp4 | March 27 | Basso Nicolae |
| PBL_MockUp_1.png | March 27 | Basso Nicolae |
| formules 2.0.pdf | March 27 | Boico Alexandr |
| formules1.0.png | March 26 | Boico Alexandr |
| calculatii_ME_Free_electromagnetic_oscilati... | March 26 | Boico Alexandr |
| calculatii_ME_Free_mecanic_oscilations.pdf | March 26 | Boico Alexandr |

**Figure 15. Materials exchanged at the beginning**

What’s more, we tried implementing formulas into MatLab programs, to see how accurate we can get our app to be in calculations and data analysis.

During the next few meetings, our mentor provided advice and useful materials, as well as some experimental data, narrowing down the field we are looking into. The team members pinpointed some aspects of the project that needed approbation or revision. We have all agreed that the meetings would take place on Microsoft Teams.

The outcome of one of the experiments is shown in Figure 16.

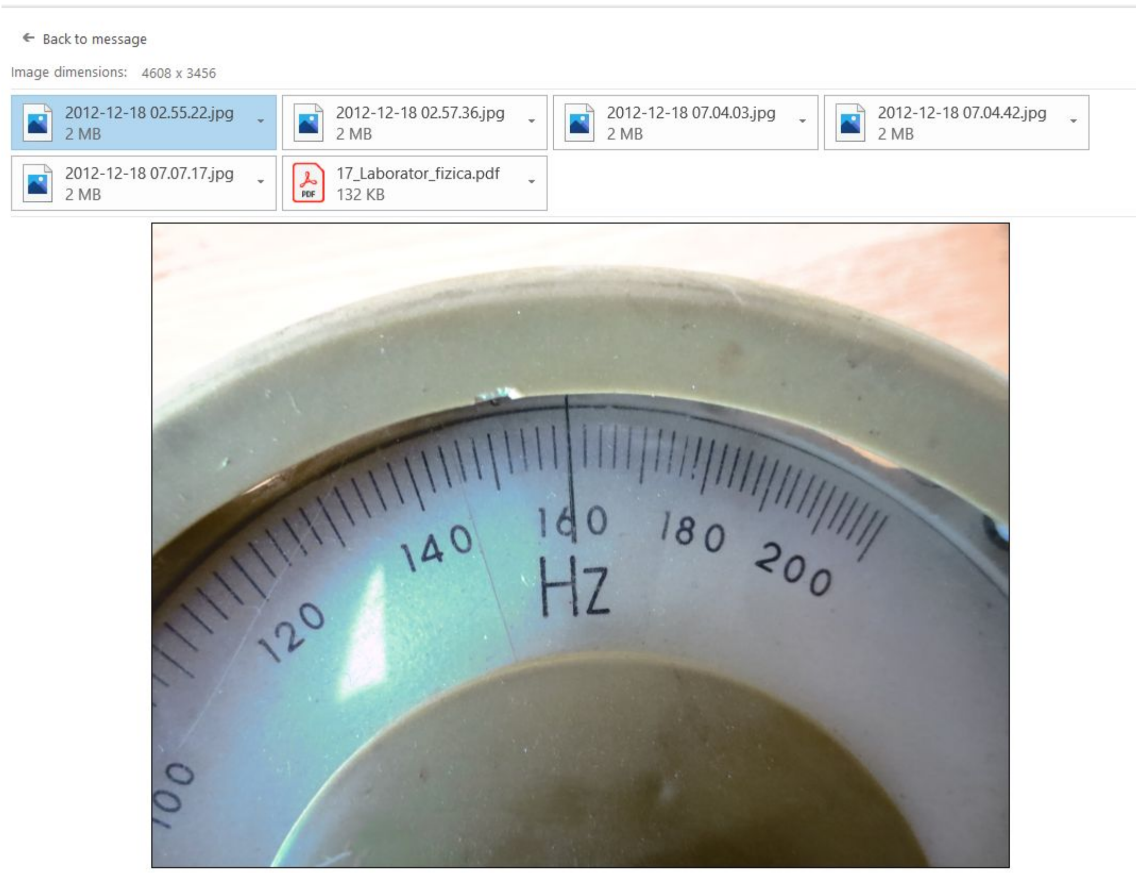
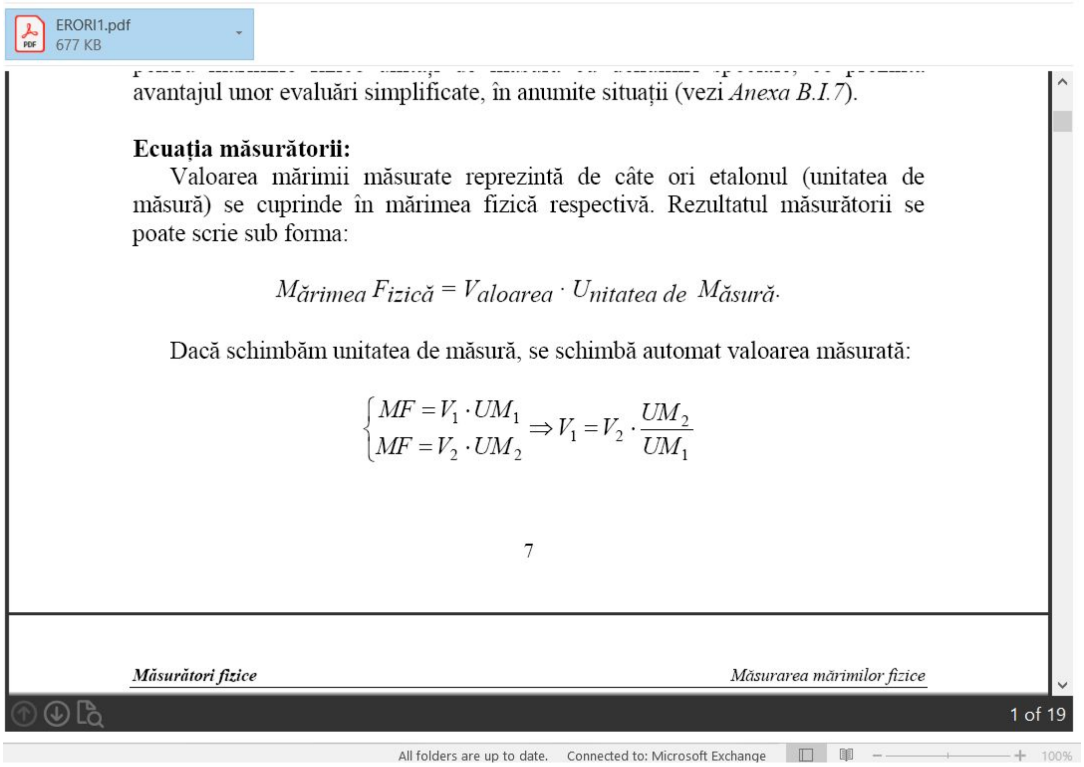



**Figure 16. Experimental data samples**

**Of course during analyzing each outcome, first of all we must take in consideration errors that occur, examples of which are shown in Figure 17.**


ERORI1.pdf
677 KB

avantajul unor evaluări simplificate, în anumite situații (vezi *Anexa B.I.7*).

**Ecuația măsurătorii:**

Valoarea mărimii măsurate reprezintă de câte ori etalonul (unitatea de măsură) se cuprinde în mărimea fizică respectivă. Rezultatul măsurătorii se poate scrie sub forma:

$$M_{ărimea}\ F_{izică} = V_{aloarea} \cdot U_{nitatea\ de}\ M_{ăsură}.$$

Dacă schimbăm unitatea de măsură, se schimbă automat valoarea măsurată:

$$\begin{cases} MF = V_1 \cdot UM_1 \\ MF = V_2 \cdot UM_2 \end{cases} \Rightarrow V_1 = V_2 \cdot \frac{UM_2}{UM_1}$$

7

*Măsurători fizice* *Măsurarea mărimilor fizice*

1 of 19

All folders are up to date. Connected to: Microsoft Exchange 100%

**Figure 17. Errors samples**

# Data and Data Analysis

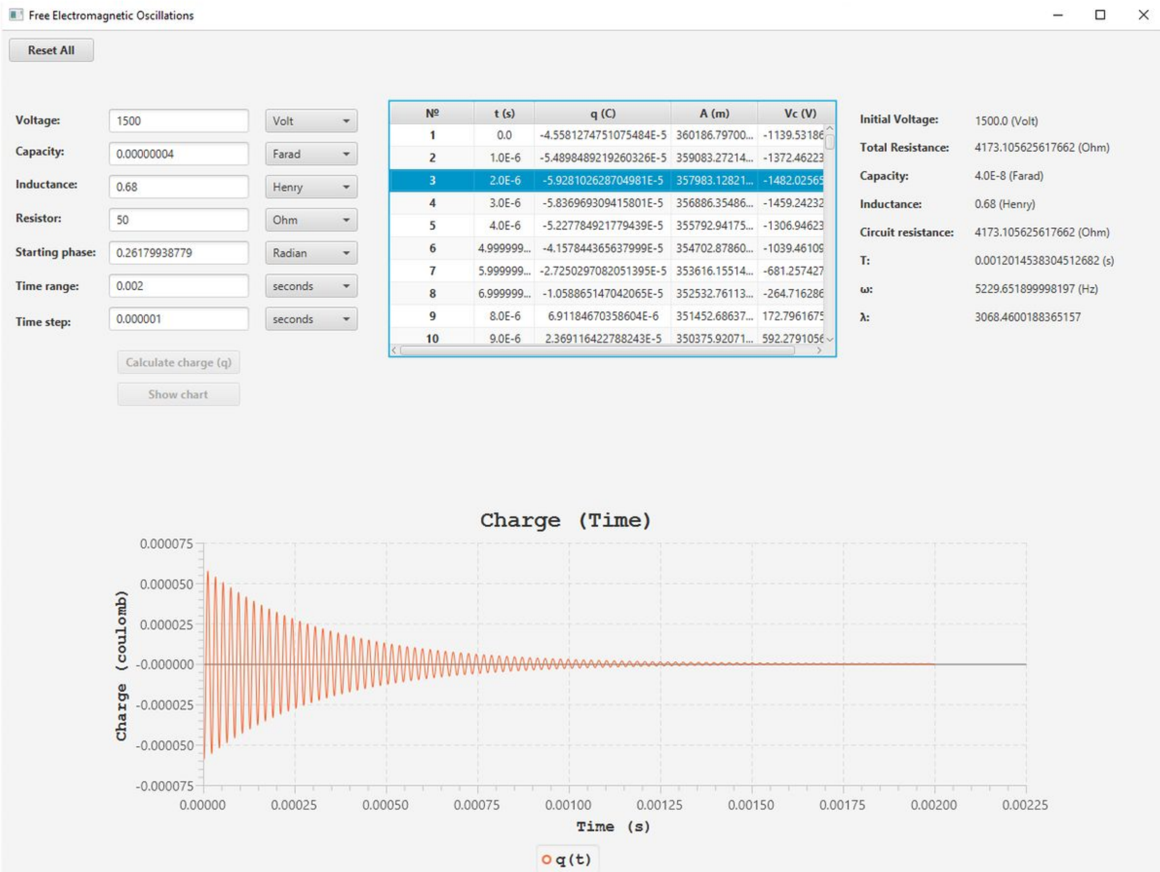
During our team meetings, we presented our work progress along the way. We have also discussed some features or aspects, as well as formulas our applications should include. For a better understandment, our mentor and our team members shared their own calculations and ideas, carefully prepared in advance.

Figure 13 presents a graphical example of the circuit that our application simulates.

# Solutions and Approaches

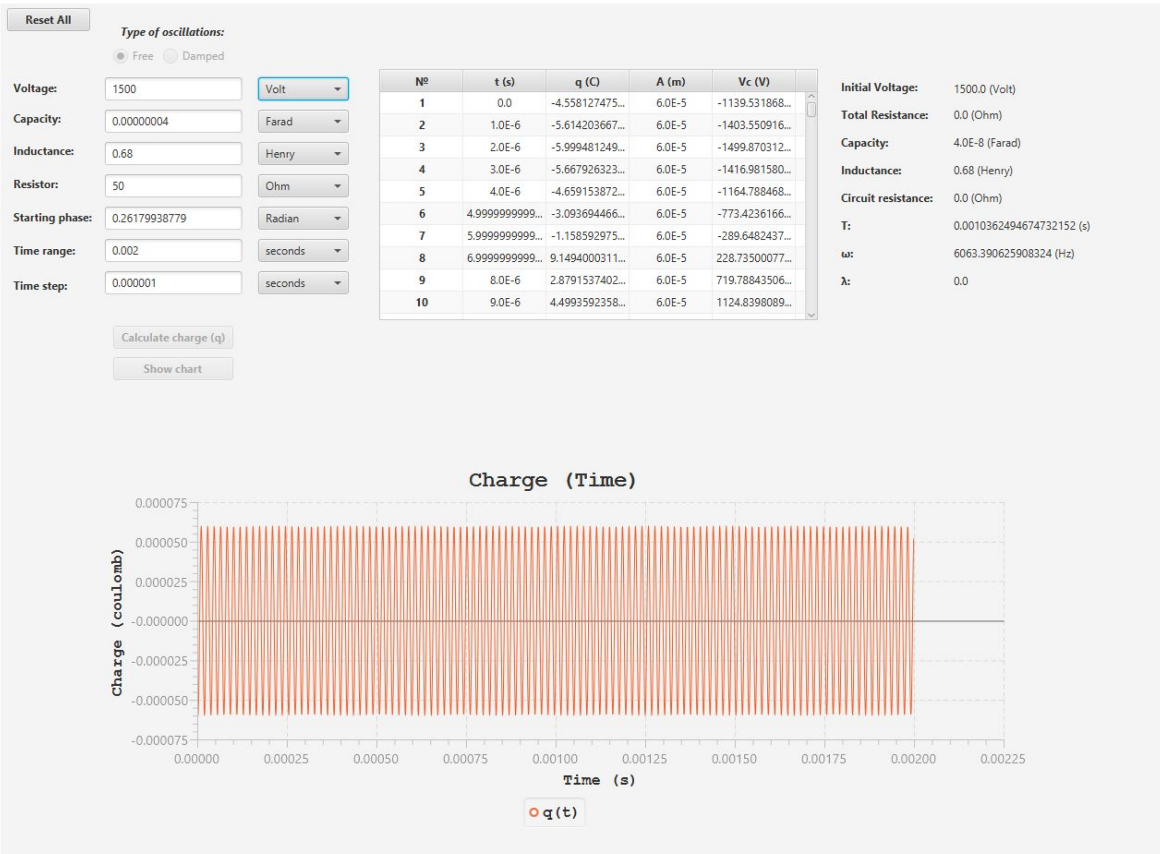
## The application:

Our team has built this app that is able to take data, analyze it and display the result. The user is able to add or remove information as they go. We tried to give the user maximum flexibility in operating with data, offering many options for each input box (Figure 18, 18.1, 18.2).




| № | t (s) | q (C) | A (m) | Vc (V) |
|---|---|---|---|---|
| 1 | 0.0 | -4.5581274751075484E-5 | 360186.79700... | -1139.53186 |
| 2 | 1.0E-6 | -5.4898489219260326E-5 | 359083.27214... | -1372.46223 |
| 3 | 2.0E-6 | -5.928102628704981E-5 | 357983.12821... | -1482.02565 |
| 4 | 3.0E-6 | -5.836969309415801E-5 | 356886.35486... | -1459.24232 |
| 5 | 4.0E-6 | -5.227784921779439E-5 | 355792.94175... | -1306.94623 |
| 6 | 4.999999... | -4.1578443656379999E-5 | 354702.87860... | -1039.46109 |
| 7 | 5.999999... | -2.7250297082051395E-5 | 353616.15514... | -681.257427 |
| 8 | 6.999999... | -1.058865147042065E-5 | 352532.76113... | -264.716286 |
| 9 | 8.0E-6 | 6.91184670358604E-6 | 351452.68637... | 172.7961675 |
| 10 | 9.0E-6 | 2.369116422788243E-5 | 350375.92071... | 592.2791056 |

**Figure 18. App interface**




| № | t (s) | q (C) | A (m) | Vc (V) |
|---|---|---|---|---|
| 1 | 0.0 | -4.558127475... | 6.0E-5 | -1139.531868... |
| 2 | 1.0E-6 | -5.614203667... | 6.0E-5 | -1403.550916... |
| 3 | 2.0E-6 | -5.999481249... | 6.0E-5 | -1499.870312... |
| 4 | 3.0E-6 | -5.667926323... | 6.0E-5 | -1416.981580... |
| 5 | 4.0E-6 | -4.659153872... | 6.0E-5 | -1164.788468... |
| 6 | 4.99999999999... | -3.093694466... | 6.0E-5 | -773.4236166... |
| 7 | 5.99999999999... | -1.158592975... | 6.0E-5 | -289.6482437... |
| 8 | 6.99999999999... | 9.1494000311... | 6.0E-5 | 228.73500077... |
| 9 | 8.0E-6 | 2.8791537402... | 6.0E-5 | 719.78843506... |
| 10 | 9.0E-6 | 4.4993592358... | 6.0E-5 | 1124.8398089... |

**Figure 18.1. Working with free oscillations**

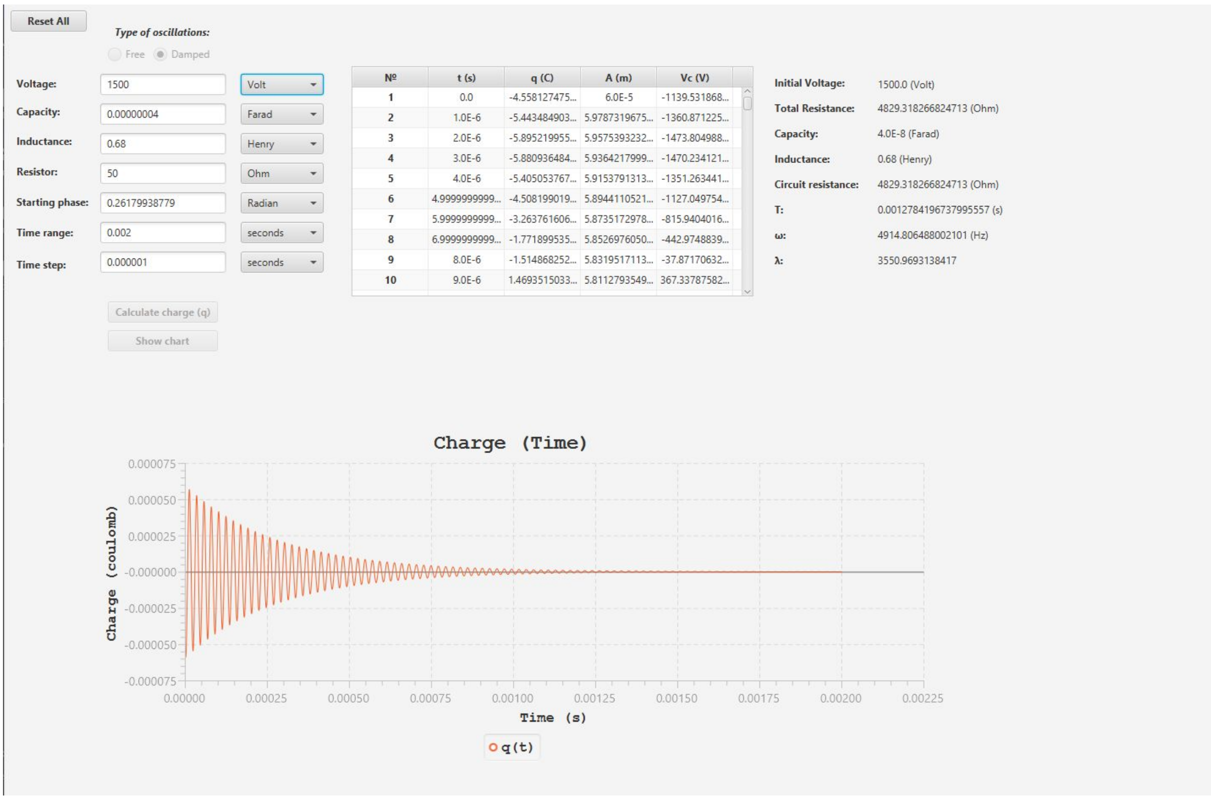



**Figure 18.2. Working with damped oscillations**

```
/*public double V;                          // starting Voltage
    public double C;                          // capacity
    public double L;                          // inductance
    public double R1;                         // auxiliary resistance

    public double Vc;                         // current Voltage
    public double amplitude0;                 // starting amplitude
    public double amplitude;                  // current amplitude
    public double omega0;                     // starting frequency
    public double omega;                      // current frequency
    public double attenuationCoefficient;     // attenuation Coefficient
    public double R;                          // total Resistance
    public double Rcrit;                      // critical (maximal) Resistance
    public double q0;                         // starting charge
    public double q;                          // current charge
    public double T;                          // oscillation period
    public double degRad;                     // ((omega*currentTime+startingPhase)*180)/pi
    public double startingPhase;              // starting Phase
    public double time;                       // time range
    public double timeDelta = 0.01;           // time step for each calculation




    public static double SpeedOfLight = 299792458;                    // speed of light
    public static double pi = 3.1415926535897932384626433832795;      // pi
    public static double epsTime = 0.0000000000000000000000001;       // error tolerance for time
```

**Figure 19.1. Declaration of the variables & constants**

```java
        R = omega0 * L + Math.pow(omega0 * SpeedOfLight, -1) + R1; //R = omega0 * L + (omega0 * c)^(-1) + R1;
        attenuationCoefficient = R/(2*L);
        //old: omega = Math.pow(L*C, -0.5);
        omega = sqrt(Math.pow(omega0, 2)-Math.pow(attenuationCoefficient,2));  // Math.pow(L*C, -1)

        Rcrit = 2 * sqrt(L / C);
        T = 2*pi/omega;
        amplitude0 = SpeedOfLight*T;    // new
        q0 = C*V;
        //amplitude = SpeedOfLight * 2 * pi * sqrt(L*C);
    }

    public void calculateCharge(){
        System.out.println("-----------------------Calculations:-----------------------");
        double currentTime = 0;
        int step = 0;

        while(currentTime + epsTime < time) {
            degRad = ((omega*currentTime+startingPhase)*180)/pi;
            amplitude = amplitude0*Math.pow(e, -attenuationCoefficient*currentTime);
            q = amplitude*cos(degRad);
            Vc = V*Math.pow(e, -attenuationCoefficient*currentTime)*cos(degRad);

            System.out.println("Charge q = " + q + "  attenuationCoefficient = " + attenuationCoefficient + " amplitude = " + amplitude + "


            step++;

            data[step][0] = String.valueOf(step);
            data[step][1] = String.valueOf(currentTime);
            data[step][2] = String.valueOf(q);
```

**Figure 19.2. Function for variable calculations**

```java
            step++;

            data[step][0] = String.valueOf(step);
            data[step][1] = String.valueOf(currentTime);
            data[step][2] = String.valueOf(q);
            data[step][3] = String.valueOf(degRad);
            data[step][4] = String.valueOf(amplitude);
            data[step][5] = String.valueOf(omega);
            data[step][6] = String.valueOf(R);
            data[step][7] = String.valueOf(attenuationCoefficient);
            data[step][8] = String.valueOf(Vc);
            data[step][9] = String.valueOf(L);
            data[step][10] = String.valueOf(C);

            currentTime += timeDelta;
        }
        System.out.println("\n\n\n" + sin(1));

        iterations = step;
    }*/
```

**Figure 19.3. Introducing data according to the index of the operation**

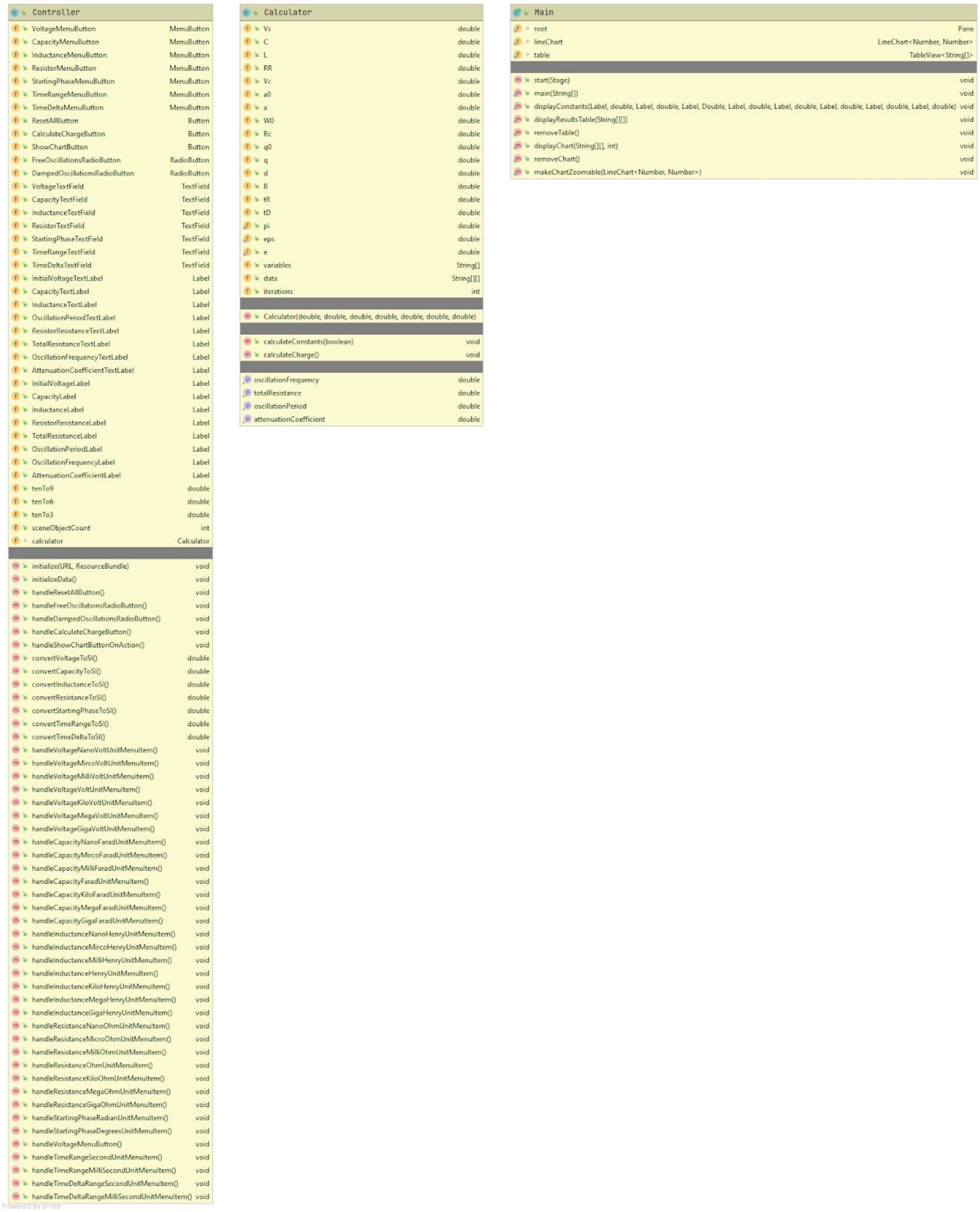



**Figure 19.3. Package Base - UML**

In Figures 19.1-19.3 are presented examples of code with specific functions. In Figure 19.1 is illustrated the process of declaring all the variables and constants. In Figure 19.2 are described functions for variable and constant calculations. Figure 19.3 - an example of data introduction according to the index of operation we want to compute. Figure 19.4 displays all the elements included in the application's workspace.

We have asked a few people to test our app and leave a review. The general feedback from them was that the GUI was nice and easy to work with. They suggest that we build a more attractive interface, which would be highly and would differentiate us from other people with similar applications.

# App Reviews

We asked a few people to test our app and share their impressions with us.

## Margareta Diacenco

***FabLab Administrator, FAF student, TUM***

“The application is very useful. I can’t believe you’ve built such an app in your first year! [...] For future updates, I suggest that you add the option of working both with damped and free oscillations at the same time. This will enable students to see the big difference between the two types of oscillations, especially with the help of graphs.”

## Cătălina Gavriliţă

***Physics teacher at T. L. “Mihail Sadoveanu”, Călăraşi***

“Amazing app! I will use it with my students. Are you planning to add some other fields of Physics to it?”

## Ştefan Damian

***.Net/C# Developer at ISD, studied at Filière Francophone "Informatique"***

"It's handy, responsive and easy to use. If I was a student, I would have used it. The interface needs some improvements, keep that in the updates list."

## Maricica Gaina

***Studies Engineering, Automatics and Informatics at "Ştefan cel Mare" University, Suceava***

"This app is very useful. Actually, it's so handy, that students might forget how to do calculations by hand and how to link the theory and the practical use of formulas when this app does it for them."

## Aryk Grosz

***Co-founder at Mixbook and CTO***

“The app it’s nice and easy to use. However, I can give some advice on the interface. First, add some space between the buttons. Then make sure no two buttons are enabled at the same time, for they will react simultaneously and may confuse the user with the results displayed on the screen. What’s more, make sure the screen is adjustable according to the width required by the data volume. You need some delimitation between each line or section. For instance, you can add some buttons which enable users to adjust the size of each section themselves, or you may simply add some lines between the sections.”

## Gheorghe Gavriliţa

***Main Engineer at “Paza de Stat”, Călăraşi***

“The app looks good. I like the graphing tool a lot! I suggest that you add this feature to your app in the future: a section which displays the circuit as the user enters the data.”

# Conclusion

To wrap up with, for this project, we did some research on free oscillations in the electromagnetic field, using an application that gave us results close to the outcomes of real experiments (sometimes even more accurate). The main advantage of this application is that there are no restrictions to where you can use it. You can simulate physical experiments wherever you are. This is extremely helpful to the students that, for some reason, are not able to attend laboratory classes. There is no need for them to worry, for they can simulate the same thing on application, and the results will be very close to the results of the outcomes of the experiences.

## General thoughts on the project

Working on this project was one of the most interesting challenges we ever met. Every team member was very enthusiastic in doing his task. We think that the work we have done here is extremely important from the scientific point of view, because the theme: „free oscillations" has a huge application in science, and the study of free oscillatory waves can lead to future discoveries, especially in electrotechnics.

This project is the proof that special situations (like quarantine) can only bring us closer to each other and great solutions can be born. It's a preparation for future obstacles that may keep people from taking all they can from performing physical laboratory work. We came up with this project in response to the thousands of people out there that are constantly unable to physically attend classes or perform a laboratory in safe conditions, as well as those people who are still in quarantine during this period of time.

# References


1. Merriam-webster, definition of free oscillation: https://www.merriam-webster.com/dictionary/free%20oscillation
2. Salfordacoustics.co.uk, Sound Waves explained: http://salfordacoustics.co.uk/sound-waves/oscillation/free-oscillations-forced-%20oscillations-and-resonance
3. Магнус К. Колебания. -М.: *МИР* 1982. -298
4. Калашников С.Г Электричество. 6 издание -М.: *ФИЗМАТЛИБ* 2003 -624
5. The application code: https://github.com/NickBasso/Physics-PBL
6. Video demonstration of our app: (copy it into the navigation bar, don’t just click) https://utm.sharepoint.com/:v:/s/PBLProject2ndSemesterFAF-191/Eax5CHUUij9FonbzN4SjIBEBNCRS_TRyumrGhNcTXqZ_hw?e=ZeniuR

# Meeting notes:

## 02.13.2020 - Mentor meeting:

- First team-mentor meeting;
- Do research on the topic;
- Bring your own ideas;
- Assign a contact person;
- We will make a physical prototype;
- Need some developers;

Members present: all

Meeting Time: 1 hour

## 02.18.2020 - Mentor meeting:

- We would use Python *meep* and *numpy* packages and MatLab for coding;
- Research on how the physical experiment goes;
- Assign team roles;
- Do some more research;
- Face time with our mentor set for Tuesdays, at 15:00

Members present: all

Meeting Time: 1 hour

## 02.19.2020 - Team meeting

- **Team roles assigned:**
  - Basso Nicolae – interface and design developer, logistics;
  - Boico Alexandr – resource investigator, secondary developer;
  - Corman Daniel – main report editor;
  - Gavrilita Anastasia – team leader; main developer; secondary report editor

Members present: Gavrilita Anastasia, Boico Alexandr, Basso Nicolae

Meeting Time: 1/2 hour

## 02.25.2020 - Mentor meeting

- The mentor handed out papers containing indications for the laboratory experiment we would do, for a better understanding of the basic concept of the project;
- Team members are working on the theoretical deductions based on the information available on the internet – optimized methods of representing wave propagation.

Members present: Gavrilita Anastasia, Boico Alexandr, Basso Nicolae

Meeting Time: 1/2 hour

## 03.14.2020 - Team meeting (online):

- We will start working on a GUI and app that simulates the flow of the electromagnetic field, according to input data from the user. The GUI will display the schematic representation of the circuit, which can also be modified in real time, according to the input from the user ("two conductors, one resistor; three resistors, two batteries etc.)
- We prepare for the conference in April – the app should be ready by then.

Members present: all

Meeting Time: 1 hour 30 minutes

## 03.21.2020 - Team meeting (online):

- Alexandr and Nicolae consult each other regarding calculations and graphical representation of the circuit;
- A prototype GUI which follows input instructions from the user has been presented and analyzed.

Members present: all

Meeting Time: 1 hour

## 03.27.2020 - Mentor meeting (online):

- Boico Alexandr continues to take care of the formulas and calculations we need throughout the project;
- Basso Nicolae is currently developing an interface for the app;

- Gavrilita Anastasia works on developing an augmented reality app that would show a fictional working station, together with electromagnetic waves coming out of it;
- Corman Daniel works on the project report.

Members present: all

Meeting Time: 1 hour

## 03.30.2020 - Team meeting (online)

- The report has suffered some changes in its template – Gavrilita Anastasia and Corman Daniel working on it;
- Boico Alexandr and Basso Nicolae sent the first screenshots of the graphics obtained through matlab interface functions;

Members present: Gavrilita Anastasia, Boico Alexandr, Basso Nicolae

Meeting Time: 1 hour 40 minutes

## 04.06.2020 - Mentor meeting (online)

- Edits in the report's template
- Tasks need to be reassigned
- The team needs to be reorganized
- Useful experimental data and materials will be uploaded by the mentor

Members present: Gavrilita Anastasia, Boico Alexandr, Basso Nicolae

Meeting Time: 1 hour + 30 minutes without the mentor

## 04.13.2020 - Mentor meeting (online)

- Tasks have been talked over – 1 coder instead of 2; 2 people will work on the report

Members present: Boico Alexandr, Corman Daniel, Gavrilita Anastasia

Meeting Time: 30 minutes

## 04.22.2929 - Mentor meeting (online)

- The current progress has been reported to the mentor

- The team members come up with ideas on how to simulate the experiments using online simulation software programs
- Minor details about our project have been discussed in particular – the report layout, which of the formulas are useful and which need to be changed etc.
- Important: some of the formulas previously computed are used in the physics of sound waves, not electromagnetic waves
- We can use Simulink and Autodesk simulators for experiments.
- All the files that have been shared up to this moment have been categorized. Subsequently, we will decide which one to keep and which ones are completely irrelevant

Members present: all

Meeting time: 30 minutes + 30 minutes (team members only)

## 04.27.2020 - Team meeting (online)

- The report has been added to: back up theory on the experiments (changes mostly made by Daniel);
- The report layout will have some features added and some taken out;
- Anastasia agreed with Alexandr and Nicolae over organizing the experimental data, as well as the results and comments in a separate Word document. They will explain their work and will emphasize on formulas used. The document will be constantly updated. Anastasia and Daniel will later incorporate the information in the report;
- We will reduce the paragraph font to 12, whilst also keeping titles on 14, bold Arial font;
- Nick will provide a link to his coded project;
- Alexandr has analyzed the already-edited report today and came up with suggestions:
    - Problem/objective: to create a user-friendly software to assist physical experiments in the domain of electromagnetism. The users will be able to simulate part of their experiment and visualize real-time updates on the experiment’s outcomes;
    - The pictures used will soon be replaced with some more descriptive ones;

- Part of the back-up theory is based on sound waves. Some of this information has to be replaced with information that targets our problem in a more specific approach, rather than a general explanation;
- Using mechanical waves oscillations as analogy to our research, rather than using the sound waves, brings more accurate assumptions about electromagnetic waves oscillations. Sound waves should still be taken into consideration when studying the propagation of waves, as well as the distance these waves can travel and their use in real life.

Members present: all

Time: 1 hour and 15 minutes

## 04.29.2020 - Mentor meeting (online)

- Alexandr and Nicolae will elaborate a separate document (and folder) where they will include everything they will be doing and describe their work in detail. Anastasia and Daniel will incorporate the information in the report.
- We will present our mentor a single file, which describes everything we work on.

Members present: Gavrilita Anastasia, Boico Alexandr, Corman Daniel

Time: 40 minutes + 30 minutes (team members only)

## 05.06.2020 - Mentor meeting (online)

- Add to the abstract: what’s the use of our product?
- Answer: for remote laboratory work (due to the pandemic or personal reasons like a physical disability)
- Nicolae and Alexandr are working on a document in which they describe their work
- Errors in calculations: due to the quarantine, our team was unable to physically experiment and build an installation related to our project; therefore, errors do not occur, because all the simulations are done on computer, no physical work is done.

Members present: all

Time: 20 minutes

## 05.15.2020 - Mentor meeting (online)

- More introduction
- Add some description to the team members' roles (½ a page for each)
- We'll organize more meetings the following week
- The whole report has to be ready by the next Tuesday

Members present: Boico Alexandr, Corman Daniel, Gavrilita Anastasia

Time: 10 minutes

## 05.20.2020 - Team Meeting (online)

- The report has to be ready by tonight
- The team members will describe themselves in the introductory part
- Some app screenshots will be included and described in the report
- Take some paragraphs out or replace them (will be discussed step-by-step)

Members present: All

Time: 40 minutes

## 05.22.2020 - Mentor meeting (online)

- Our mentor gave us advice on the report: the meeting was recorded

Members present: Boico Alexandr

Time: 30 minutes

## 05.25.2020 - Mentor meeting (online)

- Each section has to be placed on it's own page
- The presentation shall have no more than 10 slides, containing explanatory text on them
- Alexandr will create an app logo

Members present: Boico Alexandr, Gavrilita Anastasia

Time: 15 minutes

## 06.10.2020 - Team Meeting (online)

- Ideas for the app: the buttons' position, the option to work with damped oscillations, too

  Members present: all

  Time: 30 minutes

## 06.14.2020 - Team Meeting (online)

- The features previously discussed have been added to the app
- Nicolae and Anastasia worked together on reinstalling the application, using the new packages
- Anastasia will further guide other people through the installing of the app
- People like physics teachers, developers, colleagues from junior and senior years, as well as students from other engineering programs will leave a review on the app. The reviews will be included in the presentation. Their advice will be added to the future plans for the app updates.

  Members present: Nicolae and Anastasia

  Time: 1 hour 40 minutes