

Laplace Circuit Solver: A Tactile-based Educational Electronic Board Simulator for Producing Electrical Circuit's Laplace Transform Equation

Mohd Safirin Karis, Amar Faiz Zainal Abidin, Nurul Zarirah Nizam, Wira Hidayat Mohd Saad, Nursabillilah Mohd Ali, Ahmad Sayuthi Mohamad Shokri

Abstract: Laplace Transform equation is greatly used to solve the differential equation. Laplace Transform has been an integral part of the Control System, Engineering Mathematics, and Signal and System syllabus. Although the importance of Laplace Transform is significant, it can be seen that the students are still struggling with this topic. This project aims to address this by creating a low cost and interactive electronic board that translate the models the electrical circuit to its Laplace domain. The objective of this project is to provide a student to an alternative software simulator for student to simulate the electrical circuit model. This educational kit helps students to obtain the transfer function of the system from the circuit via a tactile-based educational kit named Laplace Circuit Solver. The development of the teaching aid is explained extensively where the main component used is Arduino Mega while the output is display using TFT LCD screen. The flow of this project is firstly the user need to push the push button and the green LED will on. After that, the user should insert the component and the red LED will on. During that time, the buzzer will ring. After a moment, the green LED will turn on and the screen will display the equation. Finally, the equation displayed will follow the inserted component. The teaching aid is verified by testing all the possible scenario and the result indicates that the teaching aid produce the expected output.

Index Terms: control principles; Laplace transform; educational kit; .

I. INTRODUCTION

Laplace transform is normally use to solve any problems involving the steady state AC circuit. It widely used to transform from time domain to frequency domain and vice-versa. By using Laplace transform, (LT) it uses an integral equation as a function of “t” and change to complex frequency domain. Frequency-domain (FD) based techniques represent effective alternatives to time-domain (TD) based methods for the simulation and analysis of electrical networks

[1]. A robust and accurate FD method widely used in the simulation of electromagnetic transients of power networks is the numerical Laplace transform (NLT) which comes from early research works in the 1960s [2]. Despite certain present restrictions, like the application of real-time simulation, FD methods show high precision for frequency-dependent network at low cost only of assessing algebraic equations. Furthermore, FD methods have also been successfully applied to other power components, such as transformers and motors [3, 4]. Function of this LT quite similar as phasor diagram but mostly it uses to simplify the solution of integral differential equation to manipulate set of algebraic equation using “s” domain after it transform from time domain [5]. Laplace Transform really help its user finding the best way to get to the final answer if the calculation using phasor diagram could not help them. Other Advantages of using LT is it gives systematic and routine solution for differential equation and time consuming to solve the particular equation. It has condition that the “initial condition” of the circuit will be automatically consider in transforming an equation [6]. Normally user will choose Z Transform in discrete signal while Laplace transform in continuous signal. Laplace Transform is widely used integral transform that has important application in mathematics, engineering, physics and probability theory. The theory of Laplace transforms or Laplace transformation, also referred to as operational calculus, has in recent years become an essential part of the mathematical background such as applications to ordinary and partial differential equations, integral equations, difference equations and boundary-value problems [7] required of engineers, physicists, mathematicians and other scientists. It is proven that, the calculus become the most important tool in physics for the modelling of physical phenomena [8]. Related to be great theoretical interest in itself, Laplace transform methods provide easy and effective means for the solution of many problems arising in various fields of science and engineering [7]. Laplace Transform provide an effective solution such as electrodynamic problems [9], used in modelling and simulating distributed systems with potential methods for the analysis of transient behavior of linear dynamical systems by giving fast, high accuracy [9] and accurate response [10]. It also found to reduce the truncation error in a system [11].

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As mention by V.Adamek et al [9], Laplace transform is one of the most frequently used and its inversion (ILT) is then an important step of the solving procedure. As for the university's student level, Control System is one of the subjects in engineering [12-14] that uses LT. There are many applications of LT in science and engineering world, which are analysis of electronic circuits, system modeling [15], digital signal processing [16], nuclear physics and process control. In this paper, the main application was focusing on electronic circuits. In modelling, changing the circuit condition from time domain to frequency domain is necessary using LT. User will have to face a problem to model a circuit using LT to get the transfer function since the equation only can be solve in matrix form. In the process of determining the determinant and transfer function, a lot of time will be waste since user did not have any reference answer. Therefore, if the final answer becomes unsure, the user needs more time to check the overall calculation from the start to discover the final equation. Furthermore, the usual teaching method makes it bored and not interesting to know about the topic when it comes to circuit modelling. Currently, the entire user still teaches and learns to model the circuits and to find their equations theoretically. The proposed educational kit called Laplace Circuit Solver (LCS) is one of the user's alternatives for getting a more enjoyable [17] and fast response to the modeling electrical circuit. The person who use LCS will manage to reduce time taken to find the answer. This kit is such an innovation in education and learning and can assist society to learn more, benefiting learners and teachers [18, 19]. Although this is just a straightforward kit, the effect for the user is taken into account since it makes the training method more enjoyable, becomes an attraction for the user to learn more. Laplace Circuit Solver could be find useful for universities students who are taking circuit analysis subject, Control Principles subject and secondary school students who choose electrical as their main core [20]. With this circuit solving kit, it will initiate the helpful, fun and easier understanding as practical tool to find an answer for a circuit problem [21, 22]. Laplace Circuit Solver helps a user to know more about circuit modelling in the topic of the control system. It enables the user get a response as quickly as possible. In a common classroom, the lecturers help their learners model the circuit and make it into a Laplace transforming equations. The toughest part is when the circuit becomes more complex when the component arrangement changes to different circumstances. This kit is also useful in helping the learners understand how all the possible responses can be provided, depending on how the circuit is arranged. This set can be used in teaching and learning innovations which considers all 256 circuit schemes which covered the undergraduate tertiary education level.

II. METHODOLOGY

Fig. 1 shows the top layout of the built LCS which consists of all the important components, while Fig. 2 shows the block diagram of the proposed system where Arduino Mega is used as the microcontroller for the system. The selection of Arduino Mega is heavily due to its low cost and having many Input/Output (IO) pins at disposal. Push button and Resistors are used in developing the educational board. Push button is used by Arduino to receive feedback from user. User is required to press the push button when he wants the

educational kit to provide the Laplace equation of the connected components on the top of the educational board. Location A, B, C, and D is the slots where the user can insert different electrical in order for LCS to produce the respective LT equation of the electrical circuit requested. Resistors are used as indicator of type of components inserted by the user at the specific location of the educational board. On the surface of the educational board consists of three components which written in letters: R for resistor, L for inductor, and C for capacitor. Inside the components consists of different resistor values. Resistor value of $1k\Omega$ is used to represent Resistor component. While resistors values of $2k\Omega$ and $3.3k\Omega$ are used to represent Inductor and Capacitor components respectively. TFT Liquid Crystal Display (TFT LCD) is an output component that is used to display the menu or 'splash screen' and the LT equation of the connected components when the user pressed the push button. There are two colors Light Emited Diodes (LEDs) used as indicator where Green LED is light up indicating that the educational board is ready to accept user input while Red LED will light up when the educational kit is busy processing the input and producing the output. A buzzer is an output component that is used as indicator that Arduino already accepts information from the user but also has produce output for user to view.

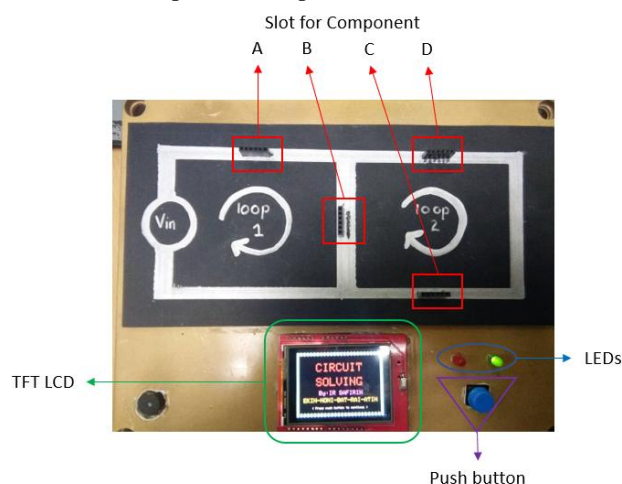


Fig. 1. Top view of LCS

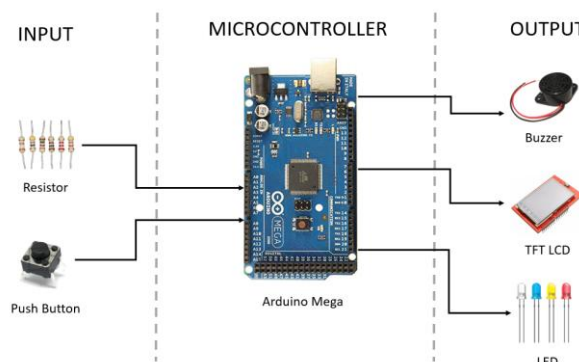


Fig. 2. Block diagram of LCS

Fig. 3 shows the flow chart of the educational board block diagram of the proposed system. When the LCS is turn ON, TFT LCD will display the 'splash screen' which indicates the title and authors of the educational board. Simple instruction for user to use LCS will be prompt accompanied by soothing tune from the buzzer.

During the displaying the 'splash screen' and running the tune, the Red LED is turn ON indicating the system is busy and will not respond if the push button being pressed. Once the tune is finished, the Red LED is turn OFF and Green LED is turn ON indicating that LCS is ready to accept user input. User is expected to install relevant components on the allocated locations. Once completed, the user is expected to press the push button. Arduino will keep looping the command to detect the push button, and once it detect the push button being pressed, it will turn ON the Red LED and turn OFF the Green LED. Then, Arduino will execute commands to detect the values of the resistors connected at A, B, C and D. Next, Arduino will respond by displaying the relevant output at the TFT LCD. Once the output is displayed at the screen, the buzzer will turn ON to attract user attention that the LCS has produced an output and the process is repeated mentioned earlier is repeated until LCS is turn OFF.

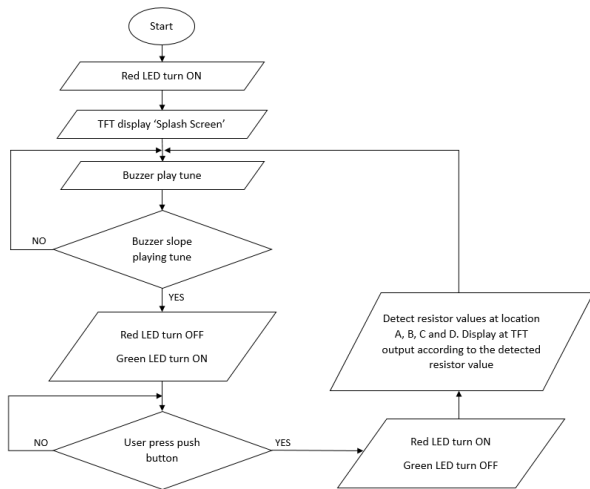


Fig. 3. Flowchart of LCS

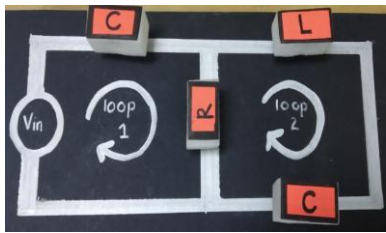
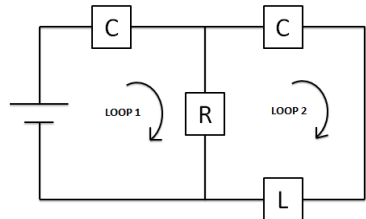
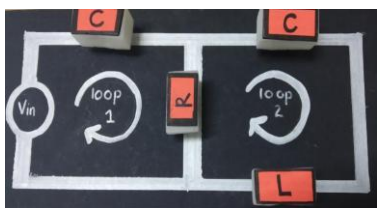
III. RESULTS & DISCUSSIONS

The prototype is tested with all scenarios which consists of 256 possible electrical connections that can be done on the board by the user. Table I shows the result of six results where all the actual results obtained are similar to the expected result. Thus, it can be said that the educational board performance is as expected.

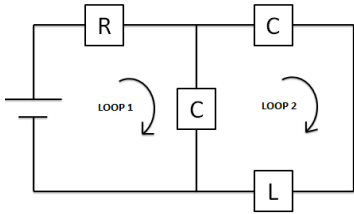
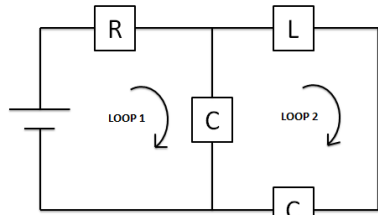
Table- I: Results of transfer functions with different component arrangement

1.	EXPECTED	CONNECTION	TRANSFER FUNCTION EQUATION	Actual result obtained similar as expected result
			<p>Loop 1</p> $V_{in}(s) = I_1(s)[R + Ls] - I_2(s)[Ls]$ <p>Loop 2</p> $0 = I_1(s)[-Ls] + I_2(s)[Ls + 2/Cs]$ <p>Matrix Form</p> $\begin{bmatrix} V_{in}(s) \\ 0 \end{bmatrix} = \begin{bmatrix} R + Ls & -Ls \\ -Ls & Ls + 2/Cs \end{bmatrix} \begin{bmatrix} I_1(s) \\ I_2(s) \end{bmatrix}$ <p>Output</p> $\frac{I_1(s)}{V_{in}} = \frac{-(Ls + \frac{2}{Cs})}{(R + Ls)(Ls + 2/Cs) - (-Ls)^2}$ $\frac{I_2(s)}{V_{in}} = \frac{(Ls)}{(R + Ls)(Ls + 2/Cs) - (-Ls)^2}$	
2.	ACTUAL	CIRCUIT CONNECTION	TRANSFER FUNCTION EQUATION	Actual result obtained similar as expected result
2.	EXPECTED	CIRCUIT CONNECTION	TRANSFER FUNCTION EQUATION	Actual result obtained similar as expected result

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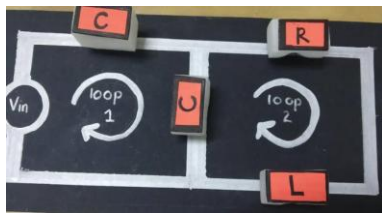
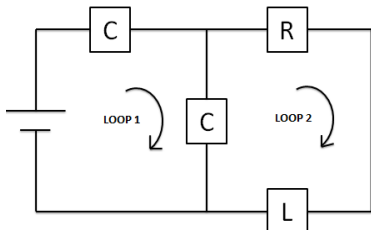

3.	ACTUAL	TRANSFER FUNCTION EQUATION	<p>Loop 1 $V_{in}(s) = I_1(s)[1/Cs + R] - I_2(s)[R]$</p> <p>Loop 2 $0 = I_1(s)[-R] + I_2(s)[R + Ls + 1/Cs]$</p> <p>Matric Form $\begin{bmatrix} V_{in}(s) \\ 0 \end{bmatrix} = \begin{bmatrix} \frac{1}{Cs} + R & -R \\ -R & R + Ls + 1/Cs \end{bmatrix} \begin{bmatrix} I_1(s) \\ I_2(s) \end{bmatrix}$</p> <p>Output $\frac{I_1(s)}{V_{in}} = \frac{-(R + Ls + \frac{1}{Cs})}{(\frac{1}{Cs} + R)(R + Ls + \frac{1}{Cs}) - (-R)^2}$ $\frac{I_2(s)}{V_{in}} = \frac{(R)}{(\frac{1}{Cs} + R)(R + Ls + \frac{1}{Cs}) - (-R)^2}$</p>
		CIRCUIT CONNECTION	
4.	EXPECTED	TRANSFER FUNCTION EQUATION	<p>Loop 1 $V_{in}(s) = I_1(s)[R + 1/Cs] - I_2(s)[1/Cs]$</p> <p>Loop 2 $0 = I_1(s)[-1/Cs] + I_2(s)[2/Cs + Ls]$</p> <p>Matric Form $\begin{bmatrix} V_{in}(s) \\ 0 \end{bmatrix} = \begin{bmatrix} R + 1/Cs & -1/Cs \\ -1/Cs & 2/Cs + Ls \end{bmatrix} \begin{bmatrix} I_1(s) \\ I_2(s) \end{bmatrix}$</p> <p>Output $\frac{I_1(s)}{V_{in}} = \frac{-(\frac{2}{Cs} + Ls)}{(R + \frac{1}{Cs})(\frac{2}{Cs} + Ls) - (-\frac{1}{Cs})^2}$ $\frac{I_2(s)}{V_{in}} = \frac{(1/Cs)}{(R + \frac{1}{Cs})(\frac{2}{Cs} + Ls) - (-1/Cs)^2}$</p>
		CIRCUIT CONNECTION	
5.	ACTUAL	TRANSFER FUNCTION EQUATION	<p>Loop 1 $V_{in}(s) = I_1(s)[R + 1/Cs] - I_2(s)[1/Cs]$</p> <p>Loop 2 $0 = I_1(s)[-1/Cs] + I_2(s)[2/Cs + Ls]$</p> <p>Matric Form $\begin{bmatrix} V_{in}(s) \\ 0 \end{bmatrix} = \begin{bmatrix} R + 1/Cs & -1/Cs \\ -1/Cs & 2/Cs + Ls \end{bmatrix} \begin{bmatrix} I_1(s) \\ I_2(s) \end{bmatrix}$</p> <p>Output $\frac{I_1(s)}{V_{in}} = \frac{-(\frac{2}{Cs} + Ls)}{(R + \frac{1}{Cs})(\frac{2}{Cs} + Ls) - (-\frac{1}{Cs})^2}$ $\frac{I_2(s)}{V_{in}} = \frac{(1/Cs)}{(R + \frac{1}{Cs})(\frac{2}{Cs} + Ls) - (-1/Cs)^2}$</p>
		CIRCUIT CONNECTION	

Actual result obtained similar as expected result

4.	EXPECTED	TRANSFER FUNCTION EQUATION	<p>Loop 1 $V_{in}(s) = I_1(s)[1/Cs + R] - I_2(s)[R]$</p> <p>Loop 2 $0 = I_1(s)[-R] + I_2(s)[R + Ls + 1/Cs]$</p> <p>Matric Form $\begin{bmatrix} V_{in}(s) \\ 0 \end{bmatrix} = \begin{bmatrix} \frac{1}{Cs} + R & -R \\ -R & R + Ls + 1/Cs \end{bmatrix} \begin{bmatrix} I_1(s) \\ I_2(s) \end{bmatrix}$</p> <p>Output $\frac{I_1(s)}{V_{in}} = \frac{-(R + Ls + \frac{1}{Cs})}{(\frac{1}{Cs} + R)(R + Ls + \frac{1}{Cs}) - (-R)^2}$ $\frac{I_2(s)}{V_{in}} = \frac{(R)}{(\frac{1}{Cs} + R)(R + Ls + \frac{1}{Cs}) - (-R)^2}$</p>
		CIRCUIT CONNECTION	
5.	ACTUAL	TRANSFER FUNCTION EQUATION	<p>Loop 1 $V_{in}(s) = I_1(s)[R + 1/Cs] - I_2(s)[1/Cs]$</p> <p>Loop 2 $0 = I_1(s)[-1/Cs] + I_2(s)[2/Cs + Ls]$</p> <p>Matric Form $\begin{bmatrix} V_{in}(s) \\ 0 \end{bmatrix} = \begin{bmatrix} R + 1/Cs & -1/Cs \\ -1/Cs & 2/Cs + Ls \end{bmatrix} \begin{bmatrix} I_1(s) \\ I_2(s) \end{bmatrix}$</p> <p>Output $\frac{I_1(s)}{V_{in}} = \frac{-(\frac{2}{Cs} + Ls)}{(R + \frac{1}{Cs})(\frac{2}{Cs} + Ls) - (-\frac{1}{Cs})^2}$ $\frac{I_2(s)}{V_{in}} = \frac{(1/Cs)}{(R + \frac{1}{Cs})(\frac{2}{Cs} + Ls) - (-1/Cs)^2}$</p>
		CIRCUIT CONNECTION	

Result obtained similar as expected result

Actual result obtained similar as expected result

6.	ACTUAL	CIRCUIT CONNECTION	
	EXPECTED	CIRCUIT CONNECTION	
	ACTUAL	TRANSFER FUNCTION EQUATION	<p>Loop 1</p> $V_{in}(s) = I_1(s)[R + 1/Cs] - I_2(s)[1/Cs]$ <p>Loop 2</p> $0 = I_1(s)[-1/Cs] + I_2(s)[2/Cs + Ls]$ <p>Matric Form</p> $\begin{bmatrix} V_{in}(s) \\ 0 \end{bmatrix} = \begin{bmatrix} R + 1/Cs & -1/Cs \\ -1/Cs & 2/Cs + Ls \end{bmatrix} \begin{bmatrix} I_1(s) \\ I_2(s) \end{bmatrix}$ <p>Output</p> $I_1(s) = \frac{-\left(\frac{2}{Cs} + Ls\right)}{V_{in} \left(R + \frac{1}{Cs}\right)\left(\frac{2}{Cs} + Ls\right) - \left(-\frac{1}{Cs}\right)^2}$ $I_2(s) = \frac{(1/Cs)}{V_{in} \left(R + \frac{1}{Cs}\right)\left(\frac{2}{Cs} + Ls\right) - \left(-1/Cs\right)^2}$
	ACTUAL	CIRCUIT CONNECTION	
	EXPECTED	TRANSFER FUNCTION EQUATION	<p>Loop 1</p> $V_{in}(s) = I_1(s) [R + 1/Cs] - I_2(s) [1/Cs]$ <p>Loop 2</p> $0 = I_1(s) [-1/Cs] + I_2(s) [2/Cs + Ls]$ <p>Matric Form</p> $\begin{bmatrix} V_{in}(s) \\ 0 \end{bmatrix} = \begin{bmatrix} R + 1/Cs & -1/Cs \\ -1/Cs & 2/Cs + Ls \end{bmatrix} \begin{bmatrix} I_1(s) \\ I_2(s) \end{bmatrix}$ <p>Output</p> $I_1(s) = \frac{-\left(\frac{2}{Cs} + Ls\right)}{V_{in} \left(R + \frac{1}{Cs}\right)\left(\frac{2}{Cs} + Ls\right) - \left(-1/Cs\right)^2}$ $I_2(s) = \frac{(1/Cs)}{V_{in} \left(R + \frac{1}{Cs}\right)\left(\frac{2}{Cs} + Ls\right) - \left(-1/Cs\right)^2}$
	ACTUAL	TRANSFER FUNCTION EQUATION	<p>Loop 1</p> $V_{in}(s) = I_1(s)[2/Cs] - I_2(s)[1/Cs]$ <p>Loop 2</p> $0 = I_1(s)[-1/Cs] + I_2(s)[1/Cs + R + Ls]$ <p>Matric Form</p> $\begin{bmatrix} V_{in}(s) \\ 0 \end{bmatrix} = \begin{bmatrix} 2/Cs & -1/Cs \\ -1/Cs & \frac{1}{Cs} + R + Ls \end{bmatrix} \begin{bmatrix} I_1(s) \\ I_2(s) \end{bmatrix}$ <p>Output</p> $I_1(s) = \frac{-\left(\frac{1}{Cs} + R + Ls\right)}{V_{in} \left(2/Cs\right)\left(\frac{1}{Cs} + R + Ls\right) - \left(-\frac{1}{Cs}\right)^2}$ $I_2(s) = \frac{(1/Cs)}{V_{in} \left(2/Cs\right)\left(\frac{1}{Cs} + R + Ls\right) - \left(-1/Cs\right)^2}$

Actual result obtained similar as expected result

Actual result obtained similar as expected result

TRANSFER FUNCTION EQUATION

Loop 1
 $V_{in}(s) = I_1(s) [2/Cs] - I_2(s) [1/Cs]$

Loop 2
 $0 = I_1(s) [-1/Cs] + I_2(s) [1/Cs + R + Ls]$

Matric Form

$$\begin{bmatrix} V_{in}(s) \\ 0 \end{bmatrix} = \begin{bmatrix} 2/Cs & -1/Cs \\ -1/Cs & 1/Cs + R + Ls \end{bmatrix} \begin{bmatrix} I_1(s) \\ I_2(s) \end{bmatrix}$$

Output

$$I_1(s) = \frac{-(1/Cs + R + Ls)}{V_{in} (2/Cs)(1/Cs + R + Ls) - (-1/Cs)^2}$$

$$I_2(s) = \frac{(1/Cs)}{V_{in} (2/Cs)(1/Cs + R + Ls) - (-1/Cs)^2}$$

IV. CONCLUSION

This paper presented the development of a teaching aid called Laplace Circuit Solver which able to translate the electrical circuit given by the user via tactile insertion of the component to its frequency domain's transfer function. The project is developed using Arduino Mega as its controller and able to simulate all 256 possible solutions successfully. Further study is still required especially in testing the effectiveness via qualitative or quantitative method of this educational kit to the target user.

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