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Integration of Hardware and Software in impedance analysis application

Ljubomir Gajić
Department of Power, Electronic and Telecommunication Engineering
Faculty of Technical Sciences, University of Novi Sad
Novi Sad, Serbia
ljubogajic6@gmail.com

Đorđe Prosenica
Department of Power, Electronic and Telecommunication Engineering
Faculty of Technical Sciences, University of Novi Sad
Novi Sad, Serbia
prosenicadjordje@gmail.com

Stojan Terzić
Department of Power, Electronic and Telecommunication Engineering
Faculty of Technical Sciences, University of Novi Sad
Novi Sad, Serbia
terzic.stojan14@gmail.com

Sara Bratić
Department of Power, Electronic and Telecommunication Engineering
Faculty of Technical Sciences, University of Novi Sad
Novi Sad, Serbia
sarabratic37@gmail.com

Dušan Marković
Department of Power, Electronic and Telecommunication Engineering
Faculty of Technical Sciences, University of Novi Sad Novi Sad, Serbia
dusanmdr@gmail.com

Marjan Urekar
Department of Power, Electronic and Telecommunication Engineering
Faculty of Technical Sciences, University of Novi Sad
Novi Sad, Serbia
urekarm@uns.ac.rs,
https://orcid.org/0000-0002-6089-9148

Abstract - This paper presents an application for analyzing signals obtained from an oscilloscope using the Python programming language. The user specifies amplitude, offset, and frequency values on their computer, and through a signal generator and oscilloscope, receives the appearance of the desired signal and impedance value. The application was developed using Python in the Visual Studio Code development environment. PySide6, PyVisa libraries, and QtDesigner were employed for creating the user interface.
Keywords: Impedance; Oscilloscope; Function Generator; Python; PySide6; PyVisa

I. Introduction

The oscilloscope [1] is an electronic instrument used for measuring and visualizing electrical signals over time. It displays the shape, amplitude, frequency, and other characteristics of the signal on the screen in the form of a graph or waveform.

A function generator [2] is an electronic device that produces electrical signals of a specified shape, amplitude, and frequency. These devices are used to generate various types of signals, including sinusoidal, square, triangular, and other waveforms.

Impedance analyzers are devices designed to measure impedance depending on characteristics (frequency range, accuracy, speed...). Their prices vary from several thousand euros and upwards. Digital oscilloscopes are affordable, and computer programs control their operation, set operating parameters, read samples, and perform analysis to obtain the modulus and phase of impedance.

Impedance measurement is the process of determining the electrical impedance of an electrical element, circuit, or system. Impedance is a complex quantity that includes the resistance (real part) and reactive (imaginary) part of the electrical circuit.

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II. Theoretical Foundations of Work

A. Block Diagram

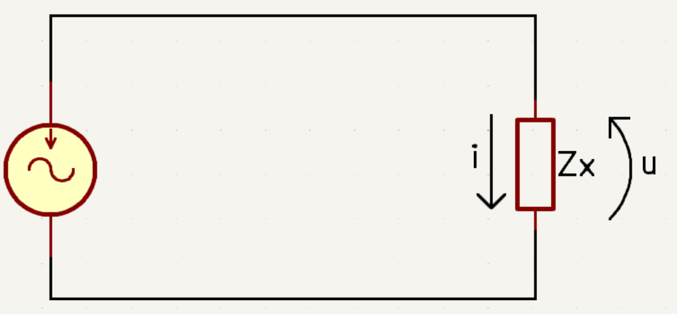

Fig. 1. Block scheme

$$Zx = U / I \quad (1)$$

In equation (1), it represents the relationship between impedance, voltage and current in an electrical circuit, where:

Zx – impedance,

U – voltage,

I - current.

The block diagram used for impedance measurement consists of the following basic components: signal source, test impedance, and impedance measurement instrument. This is a general block diagram used for impedance measurement in various applications. The signal source represents a generator of an electrical signal. It can be a signal generator that generates a sinusoidal or another signal with specified characteristics such as frequency, amplitude, and offset. The signal source sends the generated signal to the test impedance. The test impedance is a circuit or component whose impedance is measured. It can be a passive component such as a resistor, capacitor, or inductor, or a more complex active circuit.

The impedance of the test component can significantly vary depending on the frequency and offset of the signal applied to it. The impedance measurement instrument is the device that measures the response of the test impedance to the received signal. In this case, an oscilloscope is used.

Therefore, appropriate values of frequency, amplitude, and offset are set at the signal source. These parameters are sent to the test impedance, and the impedance measurement instrument records the response and calculates the impedance based on this data. Impedance is represented as a complex value that includes the real and imaginary parts to fully describe the electrical properties of the test component. It is essential to note that the block diagram and configuration can significantly differ depending on specific applications and requirements for impedance measurement.

The oscilloscope measures and displays time-domain signals in the form of points on the screen. However, when we want to analyze the frequency characteristics of a component or system, such as impedance as a function of frequency, the oscilloscope is not the most suitable instrument for that purpose.

To obtain precise impedance values at different frequencies, we employ the technique of fitting. This involves creating mathematical models (typically sinusoidal functions) that match the expected frequency characteristics of impedance. Subsequently, this model is adjusted to the measured points on the oscilloscope. Fitting in this context means adapting the mathematical model to the measured points on the oscilloscope to obtain more accurate values of amplitude and phase at different frequencies. This process utilizes mathematical algorithms (most commonly the method of least squares) to find the parameters of the model that best match the real data.

$$A + B \times \sin(2\pi f + \varphi) \quad (2)$$

Equation (2) represents the mathematical model, where:

A – offset,

B – amplitude,

f – frequency,

φ – phase.

B. Bode diagram

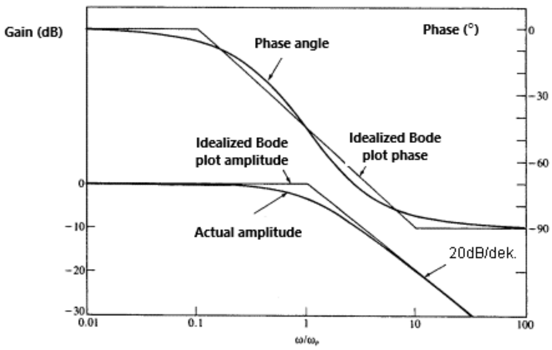

Fig. 2. Bode diagram, phase and amplitude charasteristic

This diagram is crucial for the analysis and design of electro-technical and electronic systems as it provides a clear picture of how the system will respond to different signal frequencies. It consists of two parts: the first part illustrates the amplitude characteristics of the system concerning frequency, while the second part depicts the phase characteristics. The horizontal axis features a logarithmic scale of frequencies, while the vertical axis displays amplitude (in decibels) and phase angle (in degrees).

When measuring the impedance of a test component as a function of frequency, one can observe how impedance changes with variations in the signal frequency. The Bode diagram allows these changes to be clearly visualized. On the magnitude part of the diagram, measured impedance values are shown concerning frequency in a logarithmic scale. On the phase part of the diagram, the phase angle of impedance is depicted concerning frequency.

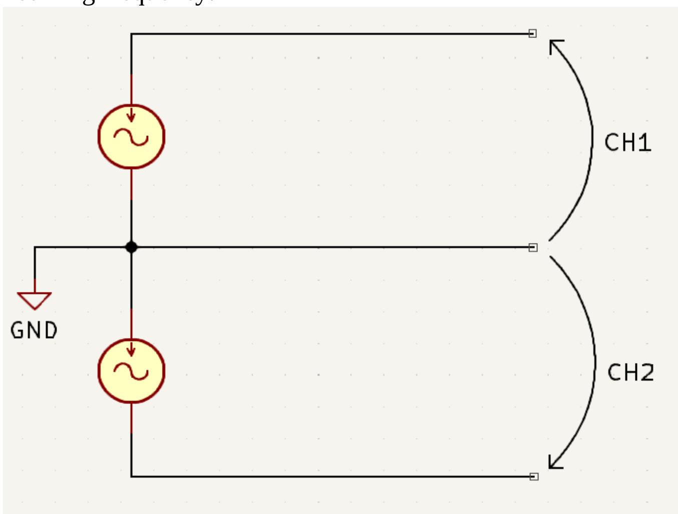

Fig. 3. The actual scheme used

Instead of directly measuring the current from the signal generator, two waveforms are generated—one on Channel 1 and the other on Channel 2 of the oscilloscope. These waveforms represent the voltage applied to the device or component whose impedance is being measured. Once these two waveforms are generated on the device or component, the oscilloscope will measure and display the device's response on the screen. Based on differences in phases, amplitudes, or other characteristics of these signals, impedance can be calculated.

The task is to provide a cost-effective version of an impedance analyzer, achieved by using an oscilloscope, signal generator, and computer. A physical oscilloscope receives electrical signals from the test impedance or signal generator. The signals are then digitized and displayed on the oscilloscope screen. It is essential to connect the oscilloscope to the computer via an Ethernet connection for data transmission. The signal generator produces electrical signals with precisely defined characteristics (frequency, amplitude, offset). These signals are then applied to the test impedance to measure the response. A USB connection is used for communication with the computer to set parameters.

After the signal generator sets the parameter values, it sends them to the oscilloscope, which displays the signal appearance on its screen based on the parameters. Then, the computer retrieves data from the oscilloscope and displays these signals and equations of the two signals on its screen. Based on two signal equations, the phase difference and impedance modulus are calculated.

III. APPLICATION DESCRIPTION

The application has been developed with the aim of enabling users to load, view, and analyze signals from an oscilloscope. Specifically, a user interface has been implemented, allowing users to input parameters via a CSV file. The interface also includes a button to initiate measurements. Within the application, users set the parameters of the signal generator through a USB connection.

The application sends these parameters to the signal generator to generate corresponding signals for impedance measurement. An Ethernet connection is utilized to collect data from the oscilloscope. This data contains the response of the test impedance to the received signals. The oscilloscope data is analyzed to determine impedance characteristics, including modulus and phase difference. This involves mathematical fitting of models to measured points. Functionality for visualizing results has been implemented, including signal display, equations, impedance modulus, and phase difference.

To make the application work, it is important to connect the oscilloscope, computer and the signal generator. In this case, in addition to Ethernet and USB connections, it is necessary to input the IP addresses of the oscilloscope and signal generator into the application for data transmission. Once a connection with the oscilloscope and signal generator is established, a CSV file containing specified parameters needs to be loaded into the application. The CSV file includes values for frequency, amplitude, and offset for both channels. Loading the CSV file satisfies all necessary conditions for the application to run. By pressing the Start button, the parameters specified in the CSV file are sent to the signal generator, configuring the values for frequency, amplitude, and offset. Subsequently, based on these parameters, signal images are obtained on the oscilloscope. The computer then retrieves data from the oscilloscope and plots the signals as points.

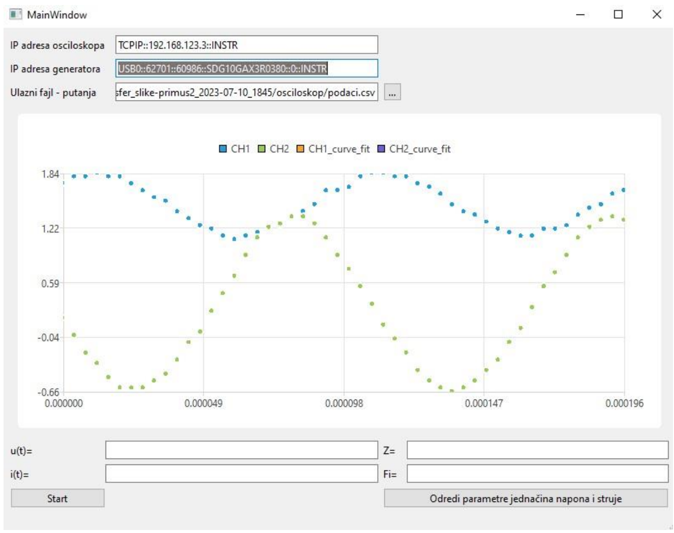

Fig. 4. Pressing the Start button

After the signal image is drawn on the oscilloscope, by pressing the button to determine the parameters, equations for both channels, as well as the modulus of impedance and phase difference, are displayed. Solid lines (fitting) are also drawn through the points to ensure that the equations are correctly displayed to the user.

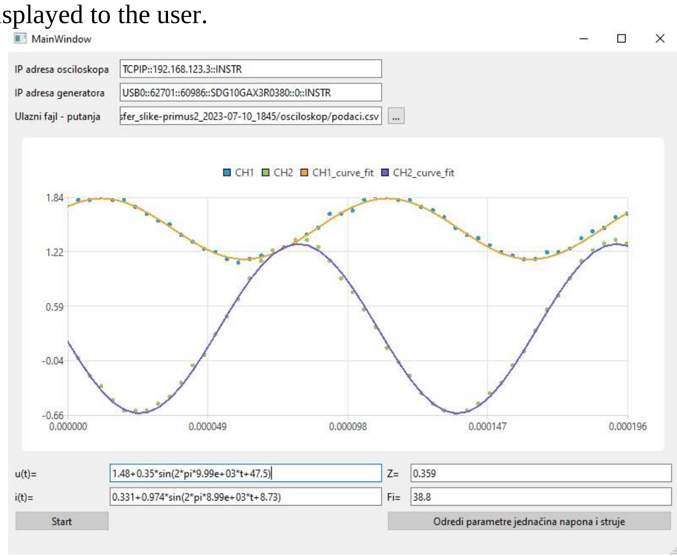

Fig. 5. Pressing the button to determine the parameters

IV. CONCLUSION

This application can be versatile in analyzing various electrical components, providing a wide range of applications. Interactive elements enable users to customize displays and analyses according to specific needs. Additionally, automatic parameter setup and analysis facilitate user work and save time. The dependence on the quality of the used devices, especially oscilloscopes and signal generators, poses a challenge. Limitations in frequency range, accuracy, and measurement speed depend on the capabilities of the used devices. The application could be used in analyzing the electrical characteristics of components, tracking how impedance changes with variations in frequency, amplitude, and offset.

It could also find applications in medical research for analyzing the electrical properties of medical devices. Another valuable use case could be in the automotive industry to characterize the electrical properties of power systems, sensors, or other electrical components in vehicles. The existing application can be enhanced by improving the user interface with the addition of interactive elements. This might include interactive graphics, controls for zooming, panning through graphs, displaying details of specific parts of the graph, and more. While there are commercial software options for analyzing electrical properties, they can be expensive. The application provides an accessible alternative, focusing on adaptability and universality. While some oscilloscopes come with integrated software, this application can be valuable for users seeking flexibility and versatility.

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