Transformers

EE 3202.002/305
Electrical and Computer Engineering Fundamentals II

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Introduction

In this lab, we are exploring transformers and their characteristics in various scenarios, such as different load impedances and input frequencies. Our goal is to gain insights into the role of transformers, particularly in AC voltage conversion, which is essential for various power applications. Transformers are widely used in devices like phone chargers and power supplies. We will analyze the outcomes using the Analog Discovery 2, aided by audio transformers, resistors, and capacitors.

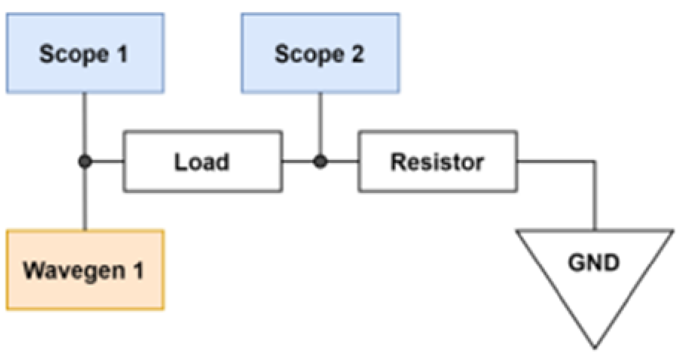
Procedure

For this lab we will be working with these materials:Audio transformer (Ration 11.5:1)

- 1 MΩ, 4.7 kΩ, 1 kΩ, 100 Ω, 50 Ω, 10 Ω, 8.2 Ω, 5 Ω and 1 Ω resistors
- Capacitor (1nF)
- Analog Discovery 2 or AD2 (Waveform generator, Oscilloscope, Network analyzer, and Impedance analyzer)
- RLC meter

To begin, insert the transformer into the breadboard and connect the waveform generator W1 to the primary side of the transformer. Simultaneously, connect CH-2 of the Oscilloscope to this same primary side. Ground the other end of the primary. Then, establish a connection from the secondary of the transformer to CH-1 of the Oscilloscope, and ground the far end of the secondary. Proceed to capture measurements using the network analyzer for both the primary and secondary sides of the setup. Afterward, replace the load and repeat the measurements using various load resistors.

Moving on to the second phase of the lab, we will assess the impedance of the transformer's secondary side. For this evaluation, we will employ the same set of resistors as before, adhering to the configuration detailed in figure 1.1 from the lab procedure. To perform this analysis, we will utilize the impedance analyzer function of AD2 and configure it to measure within the frequency range of 100Hz to 100kHz. Ensure that the impedance analyzer is set up with 10 steps per decade, yielding 31 data points. An essential step is to configure the impedance analyzer as "W1-C1-DUT-C2-R-GND."



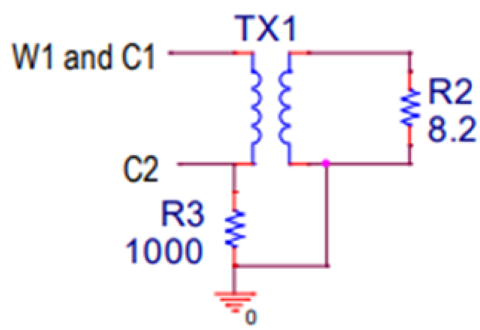


Figure 1.1 circuit schematics for AD2's Impedance analyzer

With the above configuration we measure the primary circuit input impedance for 5 different conditions (i.e., 1MW ,8.2W, 5W and 1W). As a bonus we also measures the input impedance with a capacitor.

In step 3 of the lab, the procedure mirrored step 2, but this time we focused on measuring the input impedance of the transformer's secondary side.

As for the concluding segment of this laboratory exercise, we will delve into assessing the power management within the circuit. Transformers frequently play a vital role in transmitting power from a source to a load, enhancing the efficiency of this energy transfer compared to direct power supply methods.

Lab Results

First, we assembled the circuit illustrated in Figure 1.0 and conducted a frequency sweep ranging from 100 Hz to 100 kHz. We measured magnitude and phase shift variations with different load impedances and determined their step-down ratios using data obtained from the AD2. Our findings are displayed in Figures 2.0 to 2.3 below.

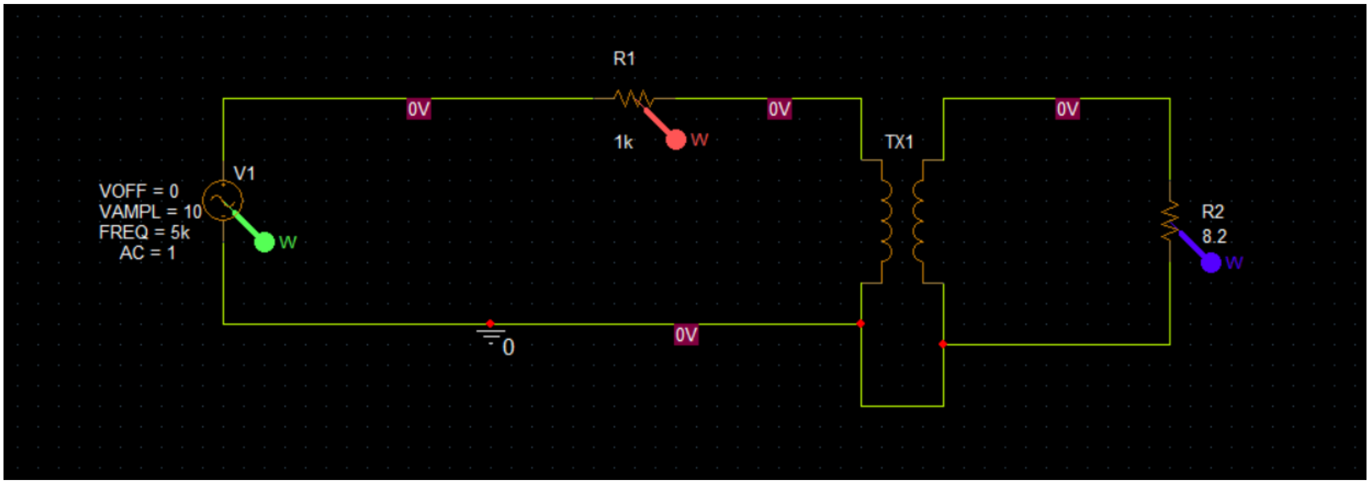


Figure 1.0 Circuit Diagram (In PSpice)

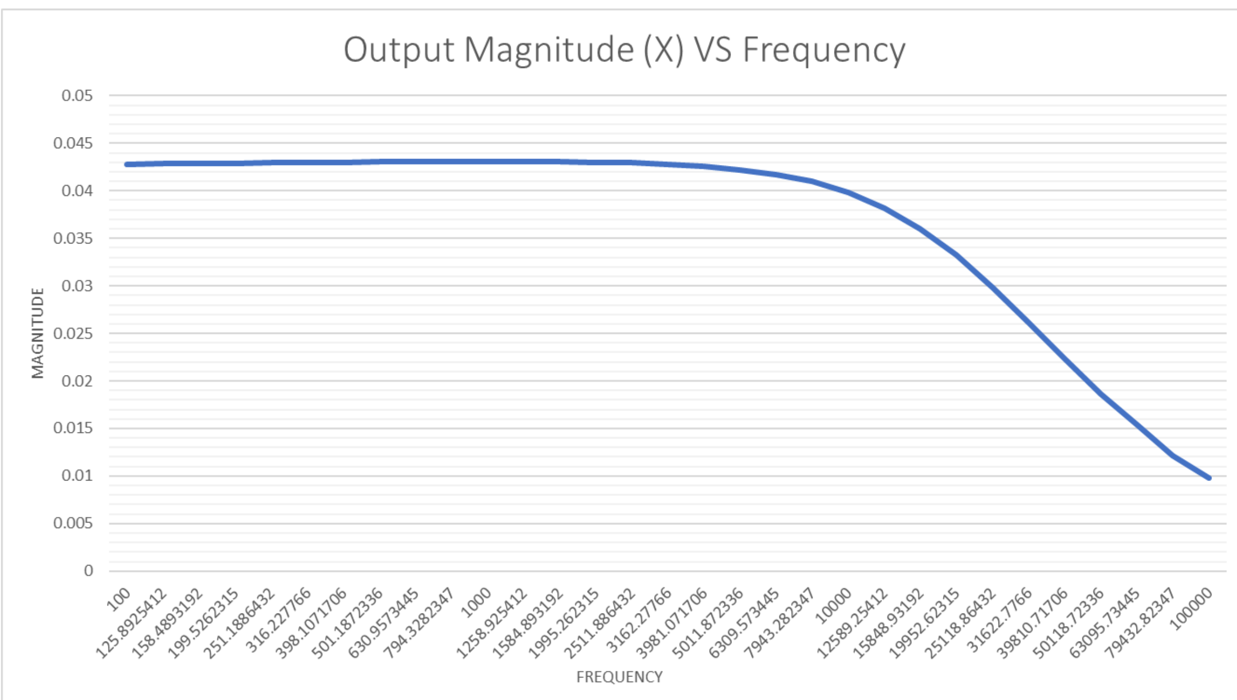


Figure 2.0a Magnitude and Frequency Graph (1 Ohm Load Impedance; Output Magnitude)

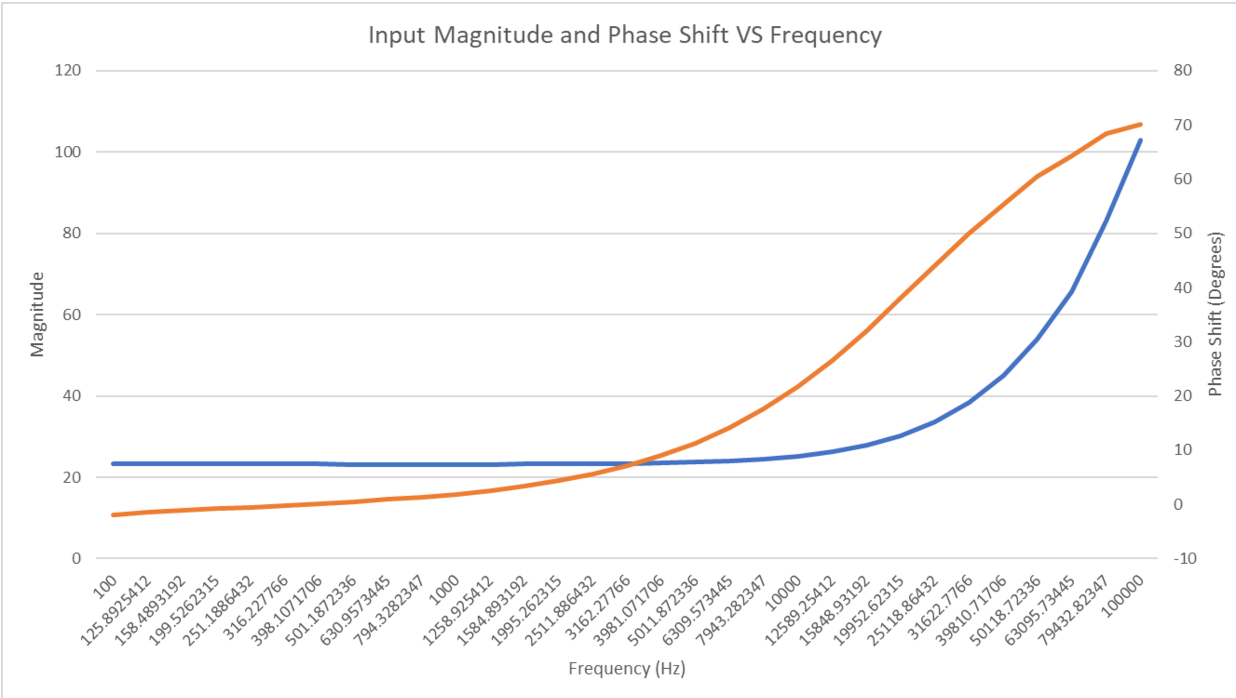


Figure 2.0b Magnitude and Frequency Graph (1 Ohm Load Impedance; Input Magnitude and Phase Shift)

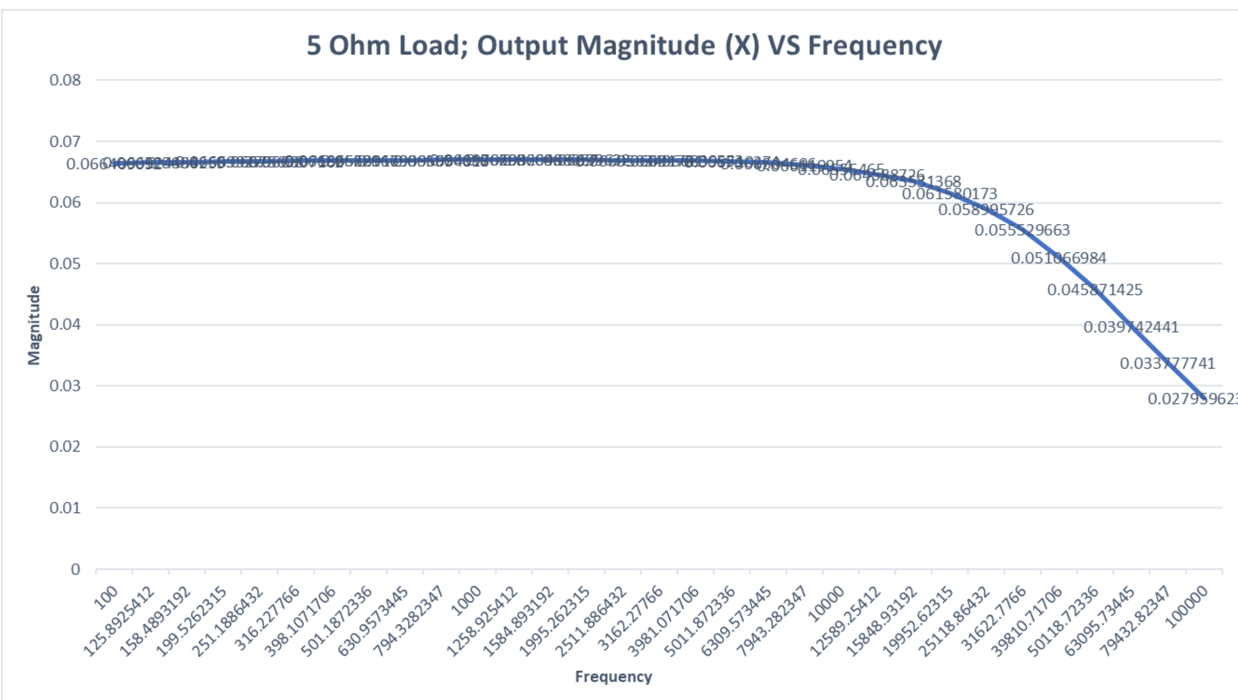


Figure 2.1a Magnitude and Frequency Graph (5 Ohm Load Impedance; Output Magnitude)

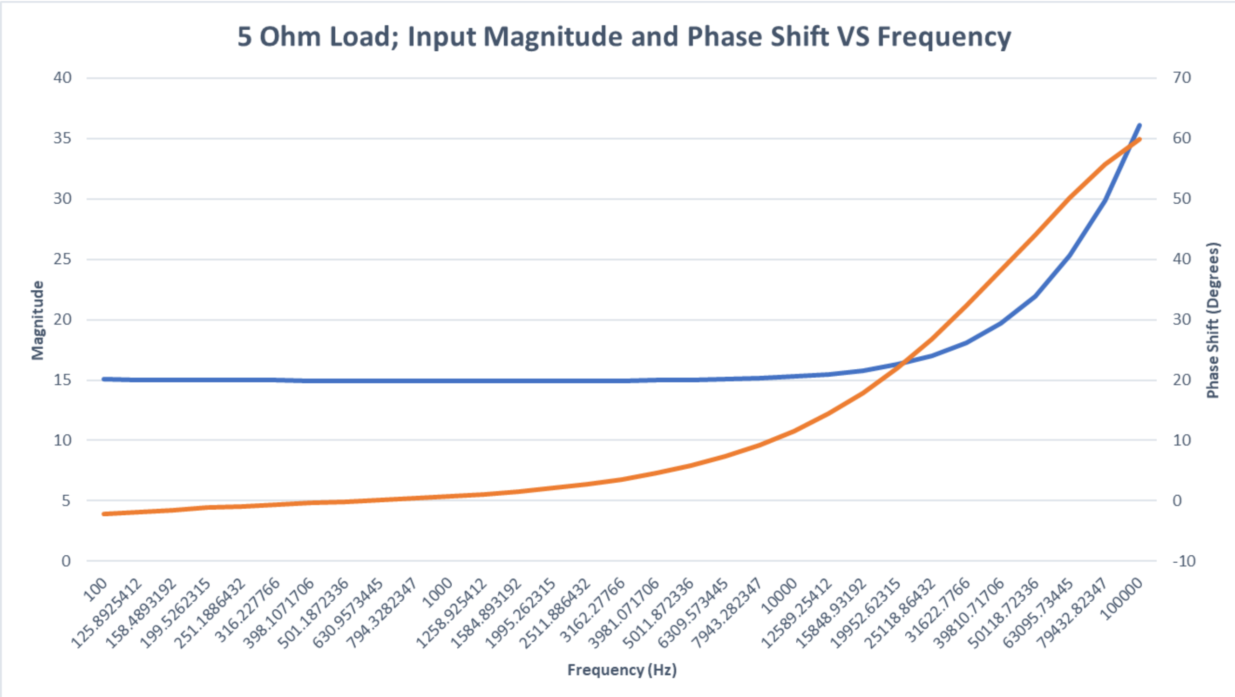


Figure 2.1b Magnitude and Frequency Graph (5 Ohm Load Impedance; Input Magnitude and Phase Shift)

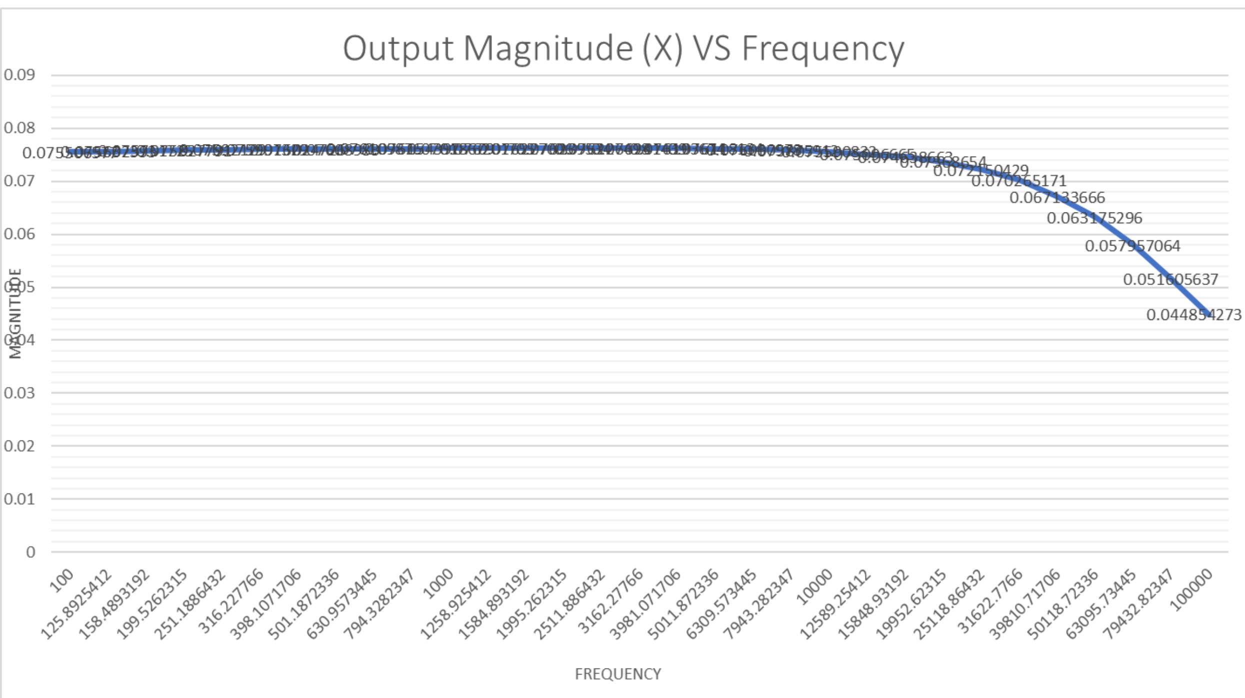


Figure 2.2a Magnitude and Frequency Graph (8.2 Ohm Load Impedance; Output Magnitude)

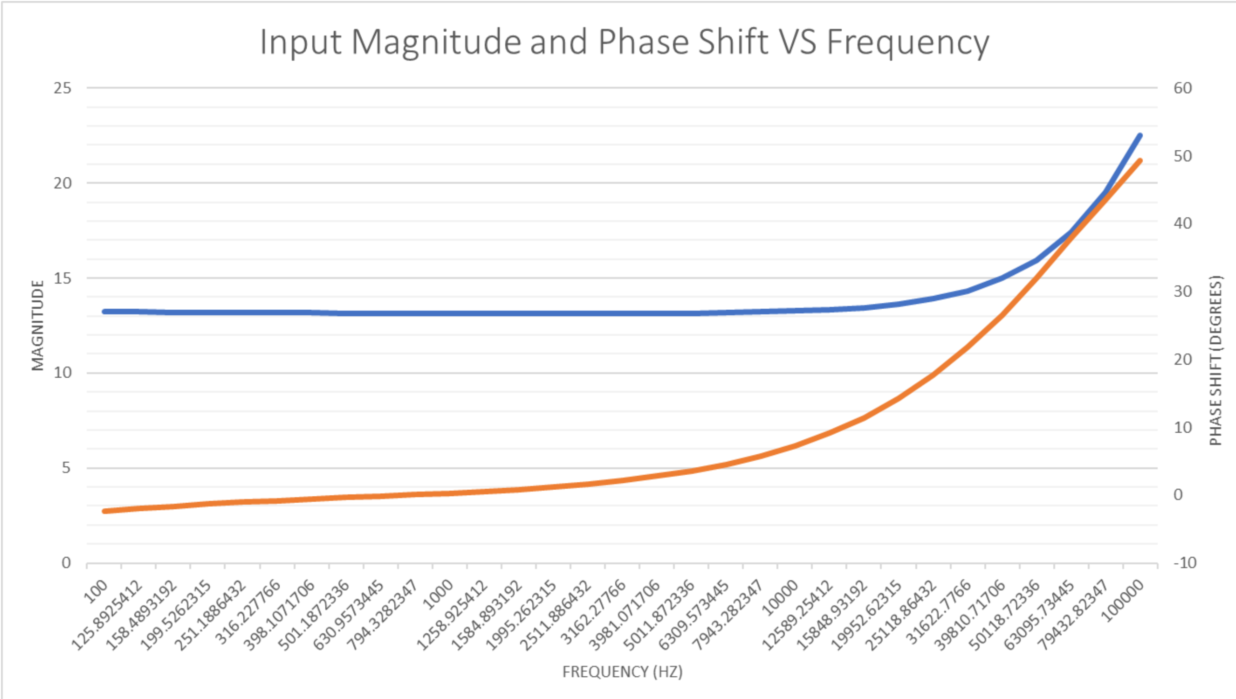


Figure 2.2b Magnitude and Frequency Graph (8.2 Ohm Load Impedance; Input Magnitude and Phase Shift)

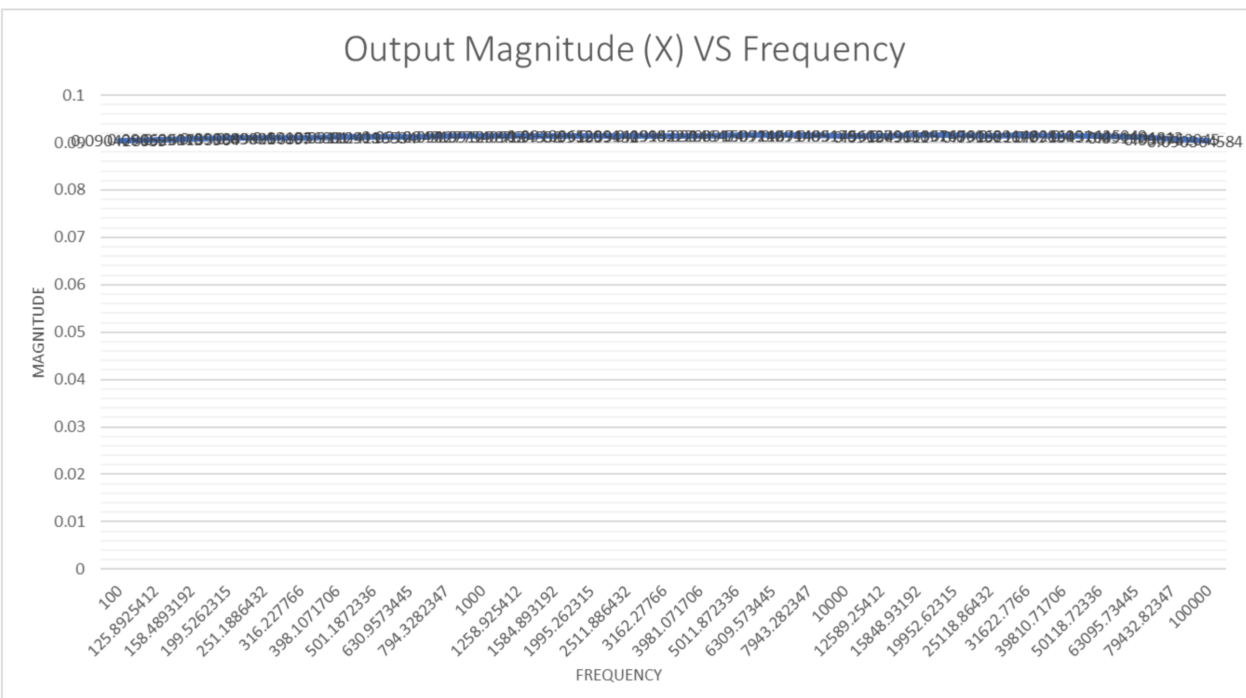


Figure 2.3a Magnitude and Frequency Graph (1M Ohm Load Impedance; Output Magnitude)

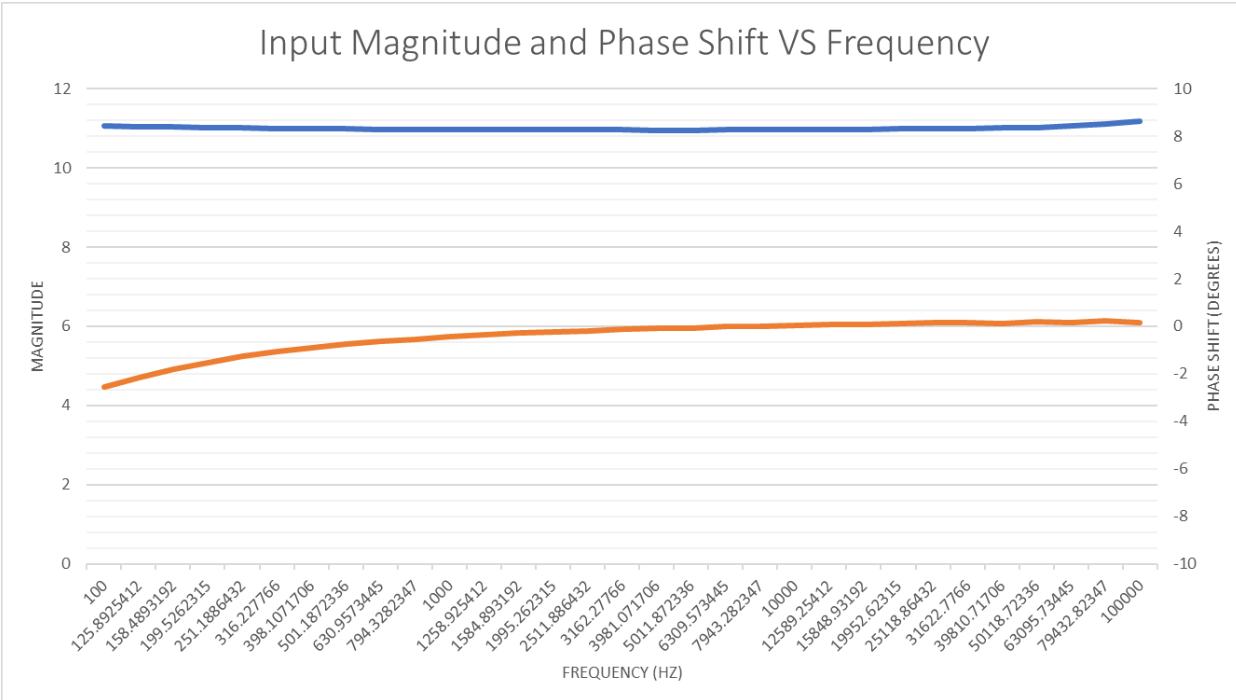


Figure 2.3b Magnitude and Frequency Graph (1M Ohm Load Impedance; Input Magnitude and Phase Shift)

The provided plots reveal that load impedance does indeed impact the magnitude. To simplify, when load impedance increases, magnitude remains constant, and there is minimal to no phase shift. Next, we will utilize the amplitudes to calculate the inverse step-down ratio and investigate whether there is any correlation based on frequency or load impedance.

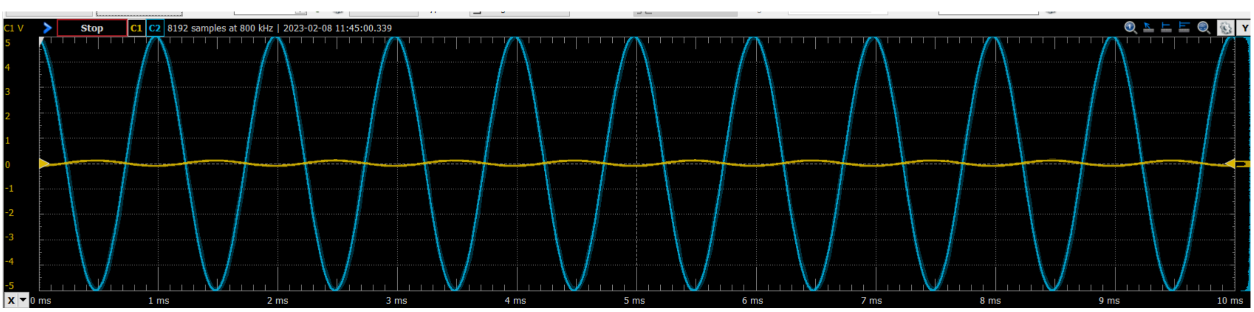


Figure 3.0 Amplitude Waveforms (1 Ohm Load; Yellow is Output, Blue is Input)

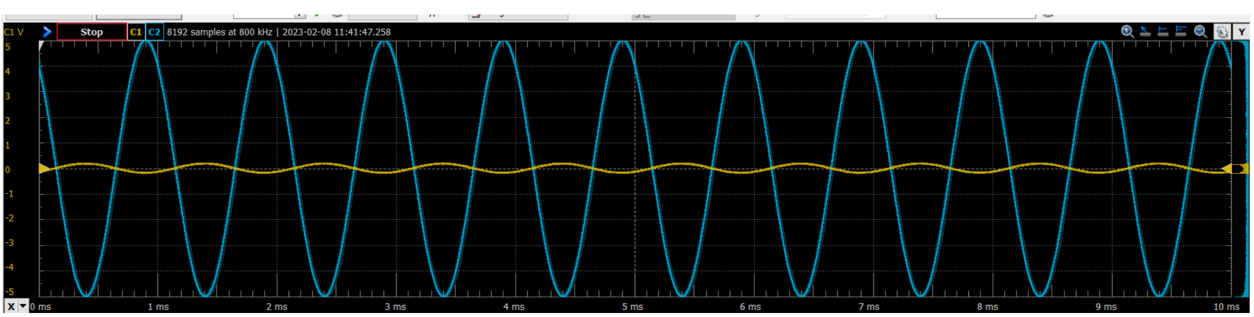


Figure 3.1 Amplitude Waveforms (5 Ohm Load; Yellow is Output, Blue is Input)

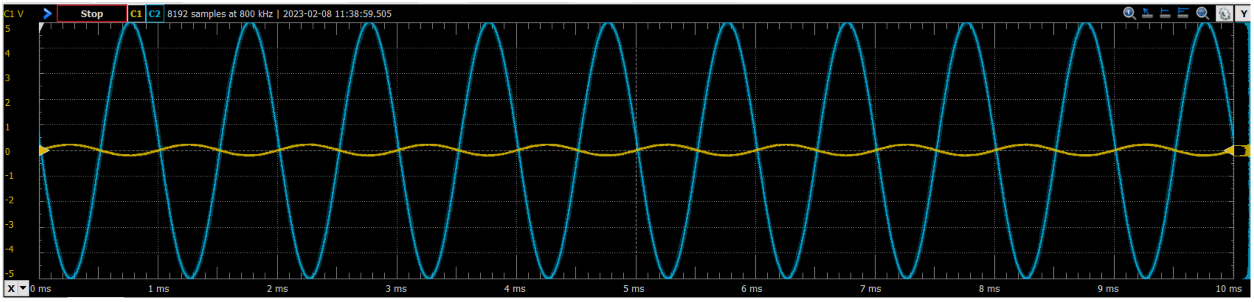


Figure 3.1 Amplitude Waveforms (5 Ohm Load; Yellow is Output, Blue is Input)

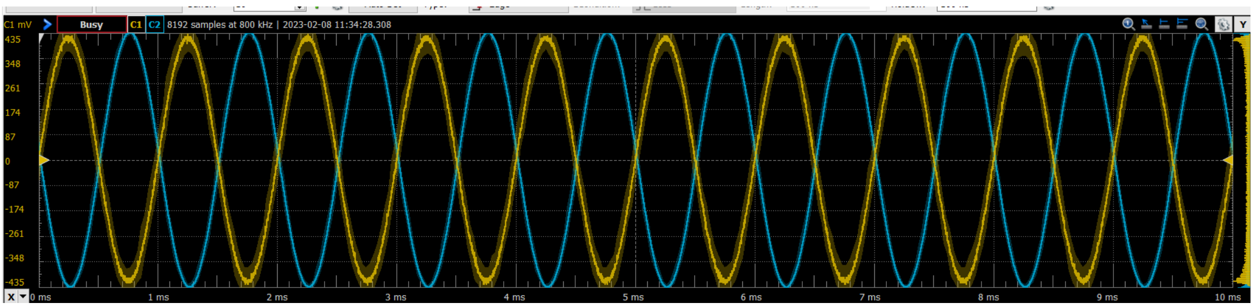


Figure 3.2 Amplitude Waveforms (1M Ohm Load; Yellow is Output, Blue is Input)

As evident from the graphs, they all share a consistent amplitude. However, for the final measurement, we opted to magnify the amplitude to analyze the relationship between the graphs. It's worth noting that as the load increases, the phase shift also increases. When we consider a maximum input amplitude of 5V, we observe that the output reaches a peak of 435mV. If we perform the calculation of Channel 2 divided by Channel 1, the resulting value is approximately 11.494

The anticipated inverse of the step-down ratio from the pre-lecture reading was provided as 11.5. Upon conducting our calculations, we obtained a value of 11.49, which displayed that our transformer setup is operating as anticipated. Our findings demonstrate that the step-down ratio is affected by both frequency and load impedance. Furthermore, the stability of the step-down ratio within a specific frequency range is dependant upon the load impedance.

From here, we will take a look at the impedance from both sides of the transformers (Figs 4.0 - 4.4). We performed some calculations to find the expected input impedance for all the different loads using the formulas given in our pre-lab.

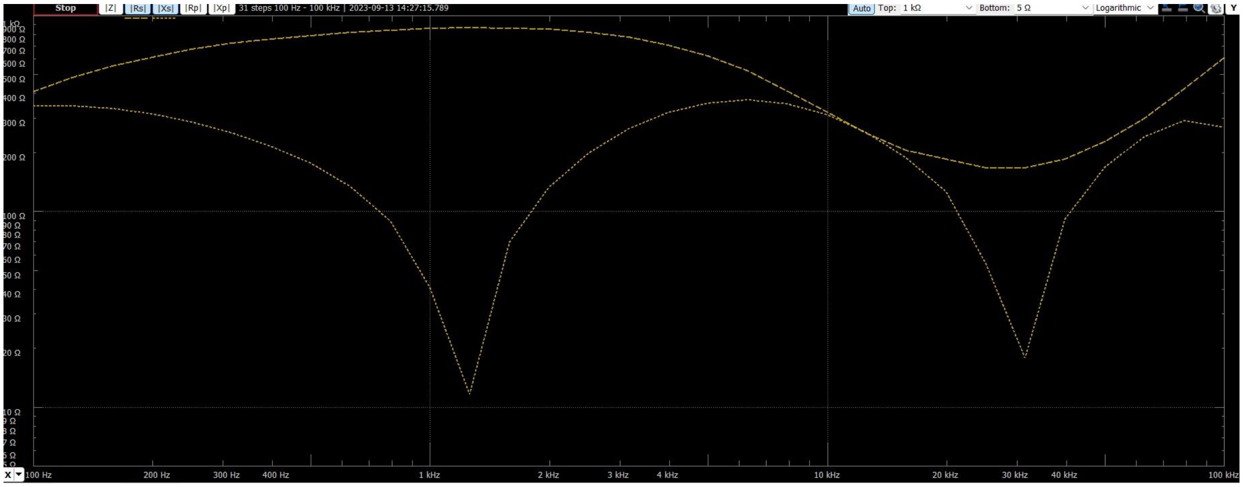


Figure 4.0 Input Impedance Frequency Sweep (1M Ohm Load)

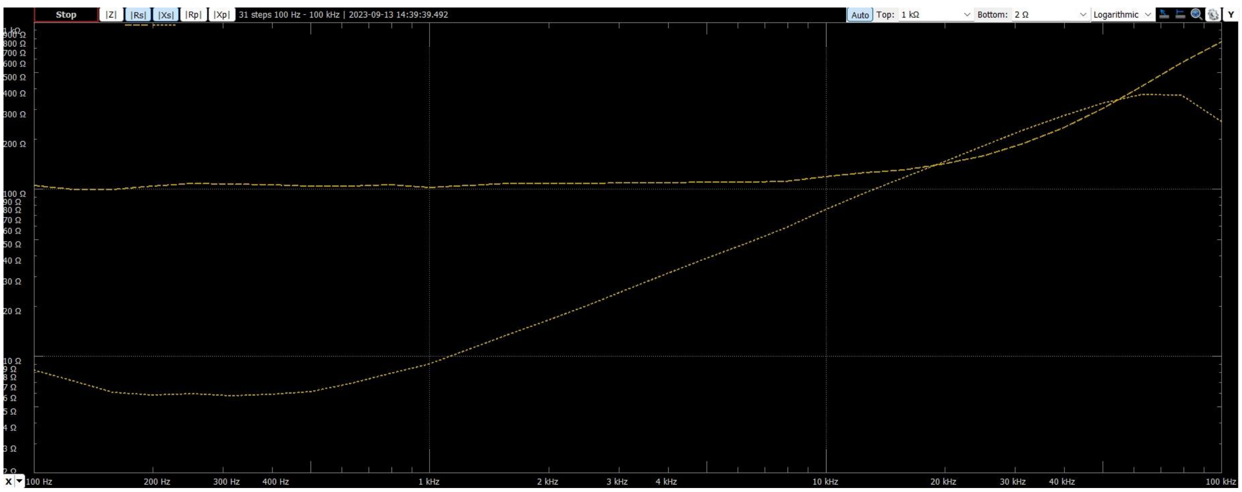


Figure 4.1 Input Impedance Frequency Sweep (Shorted Load)

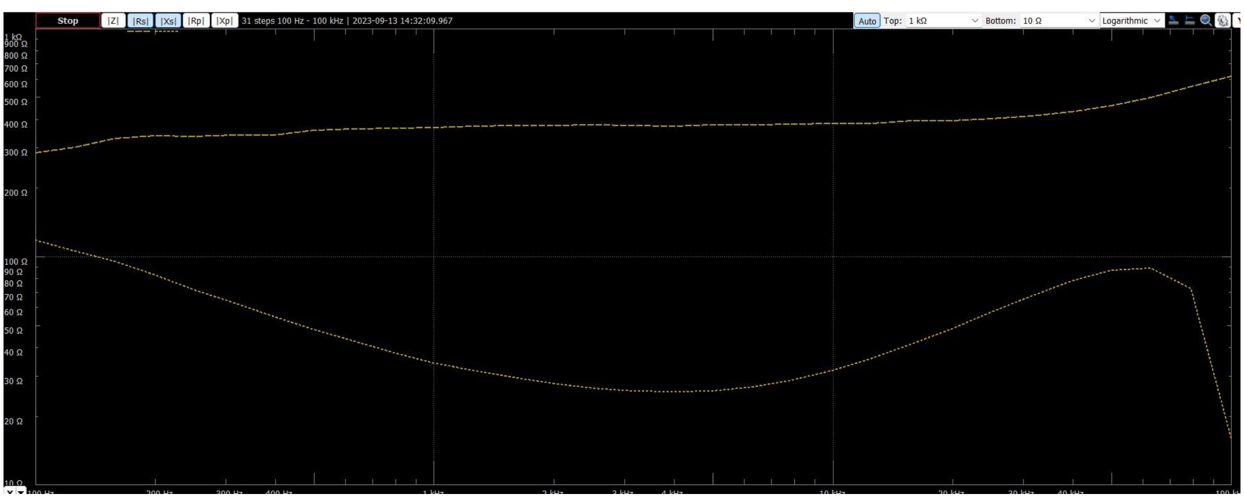


Figure 4.2 Input Impedance Frequency Sweep (8.2 Ohm Load)

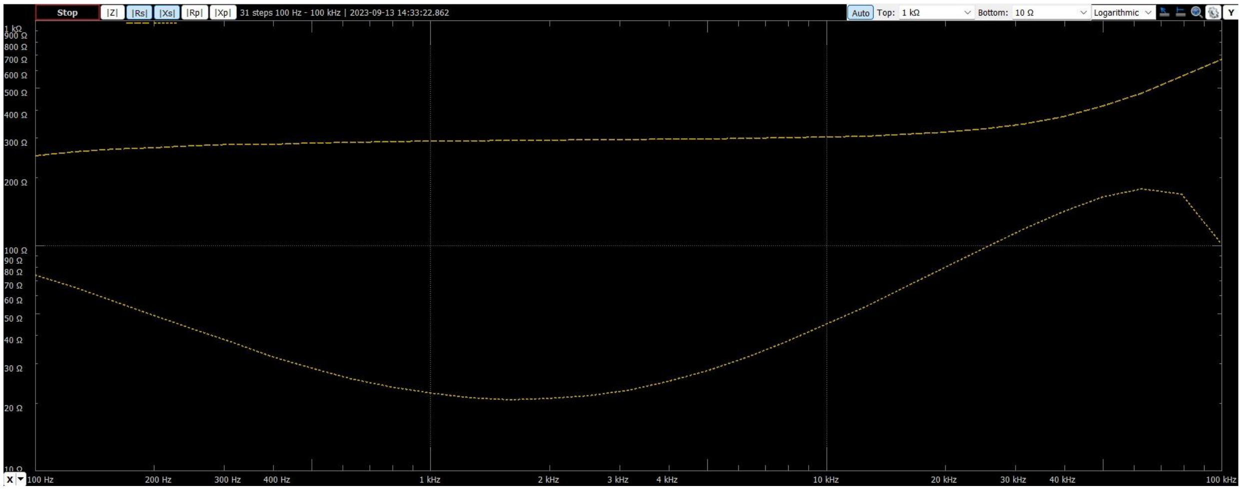


Figure 4.3 Input Impedance Frequency Sweep (5 Ohm Load)

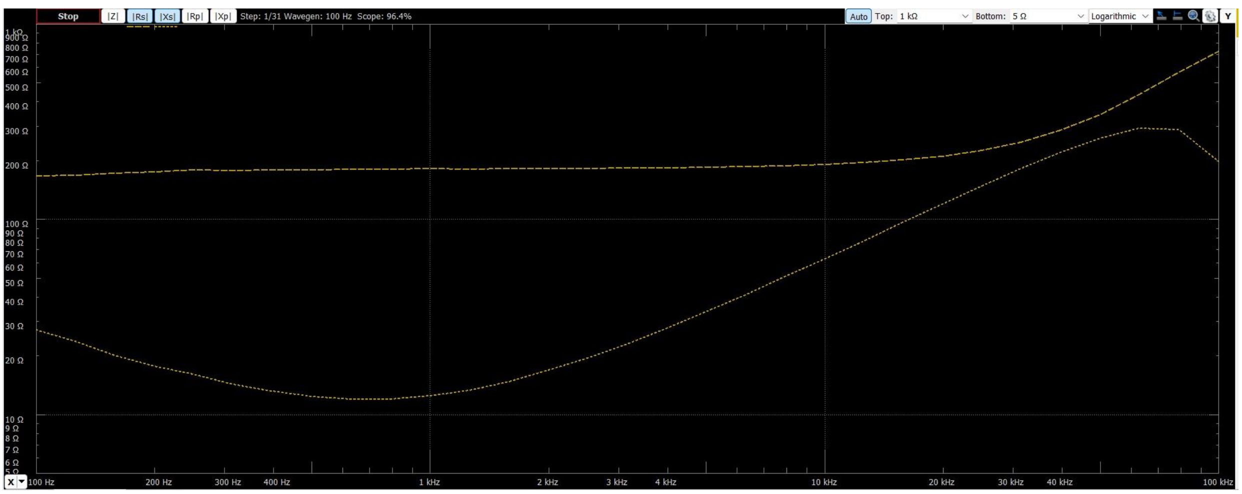


Figure 4.4 Input Impedance Frequency Sweep (1 Ohm Load)

Now let us calculate the expected output impedance for all the loads and compare our calculations to our results.

$$Img(Z_1) = j\omega X_1 = j\omega\left(L_1 - \frac{(\omega M)^2 L_2}{(\omega L_2)^2 + Z_L^2}\right) \tag{5}$$

$$Re(Z_1) = R_1 = \frac{(\omega M)^2}{(\omega L_2)^2 + Z_L^2} Z_L \tag{6}$$

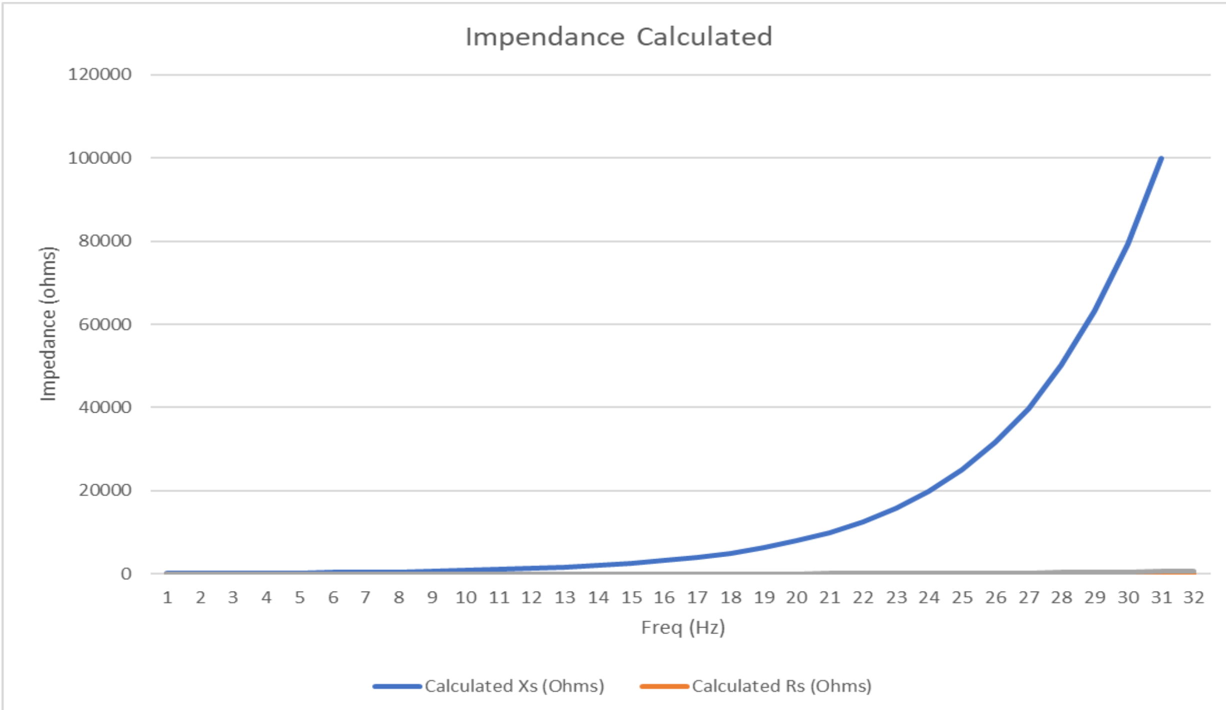


Figure 4.5 Input Impedance Calculations (Shorted Load)

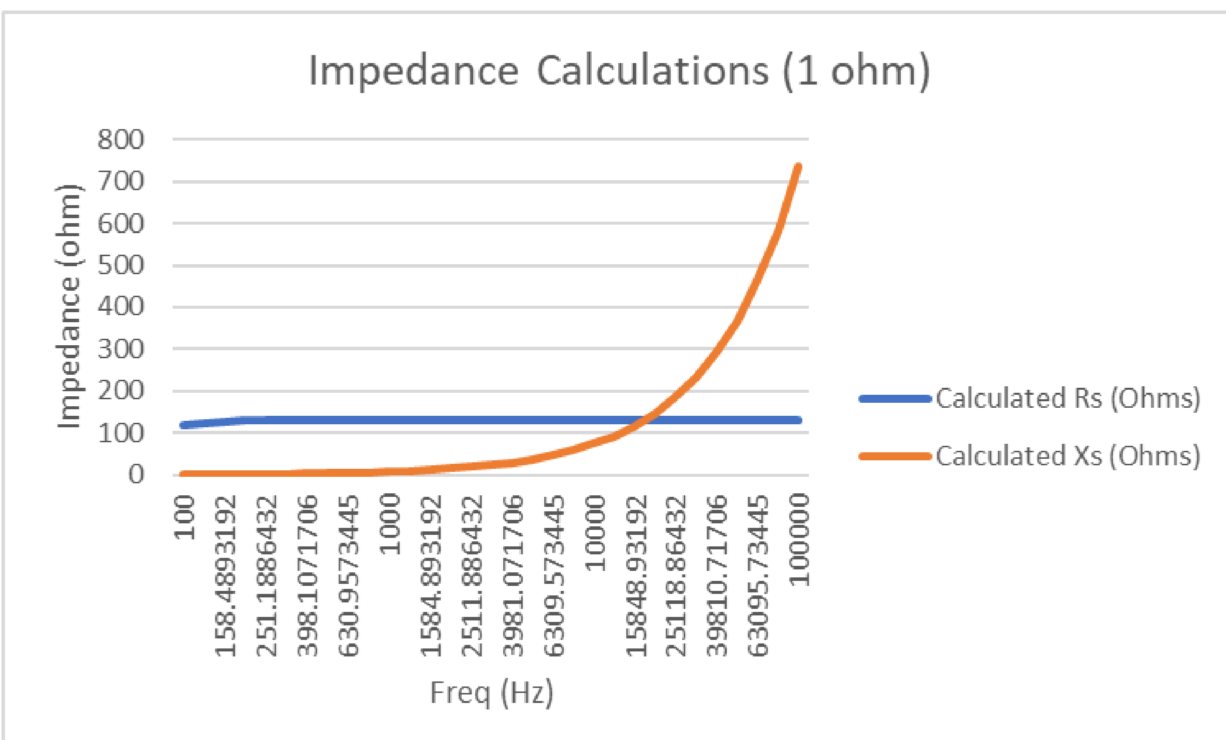


Figure 4.6 Input Impedance Calcualtions (1 ohm)

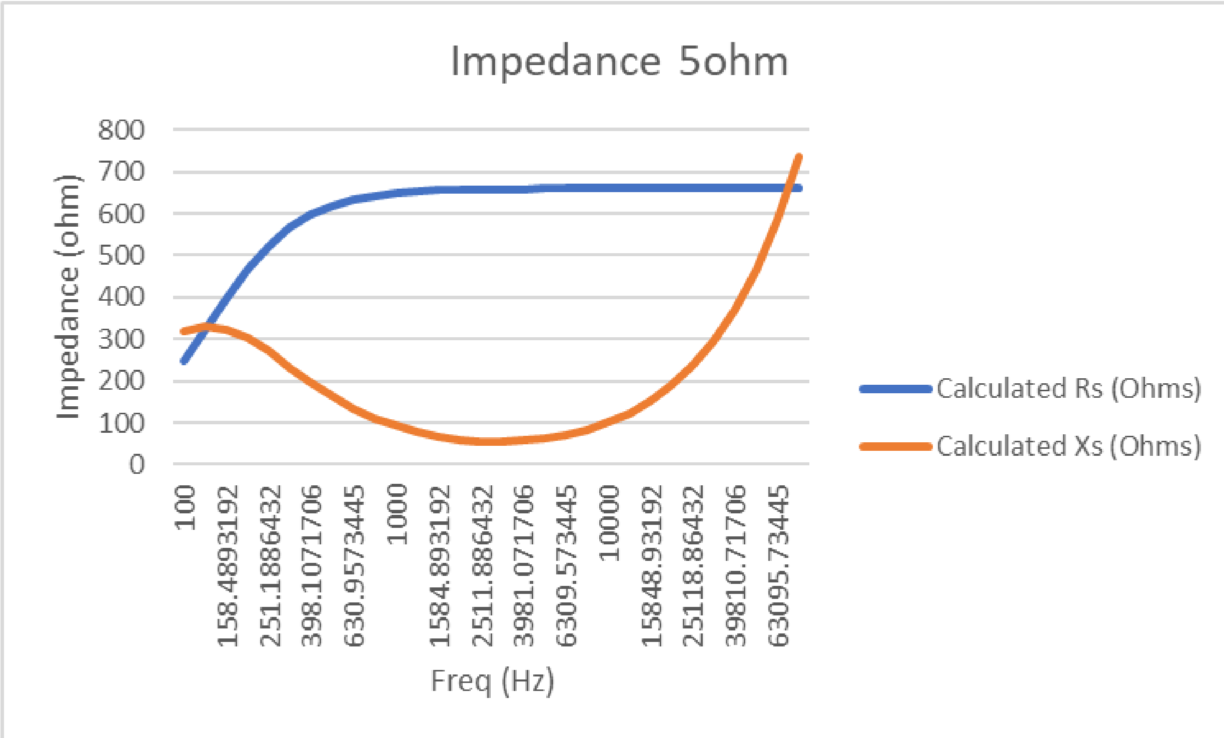


Figure 4.7 Input Impedance Calcualtions (5 ohm)

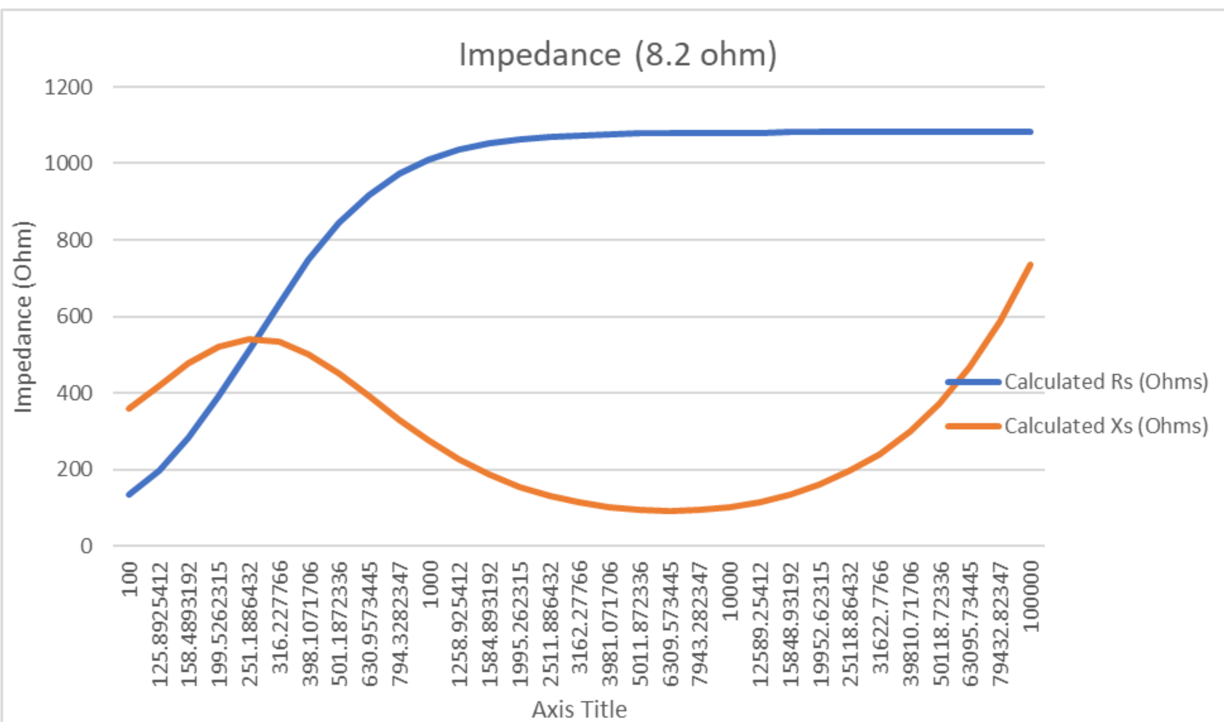


Figure 4.8 Input Impedance Calcualtions (5 ohm)

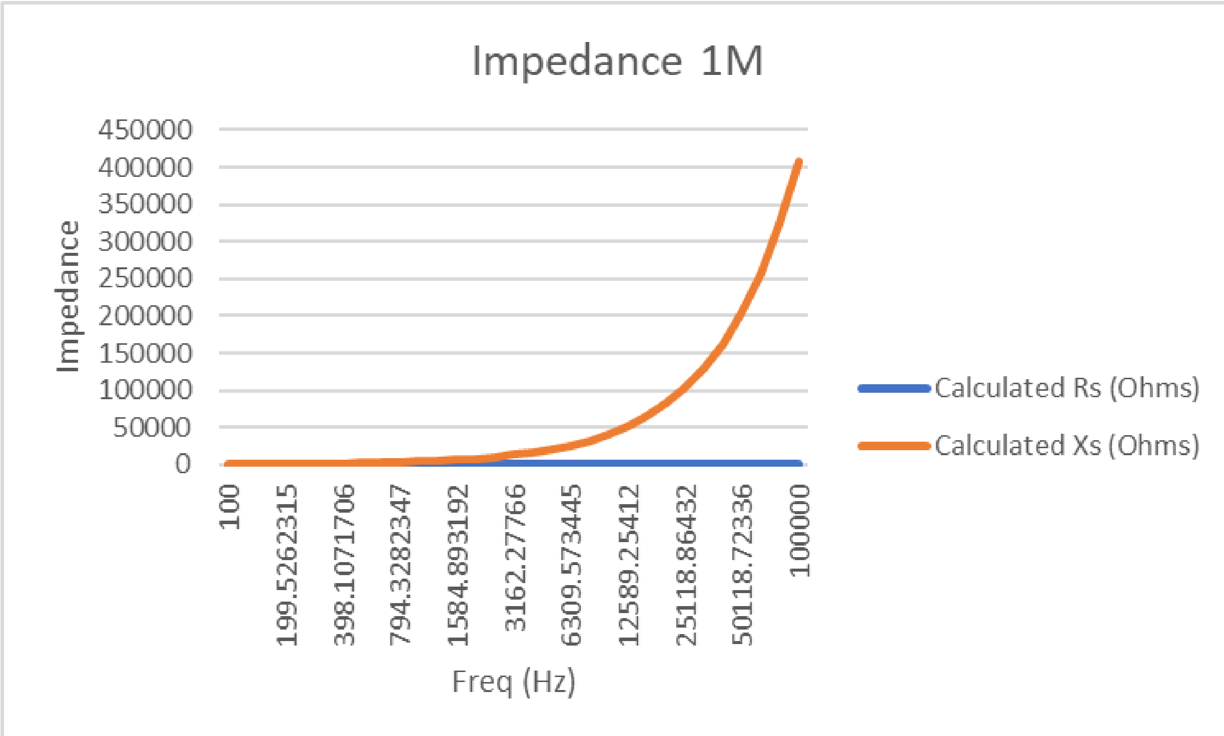


Figure 4.9 Input Impedance Calcualtions (1M ohm)

In general, the excel plots and our calculations show a trend of similarity with an exception to the 1M ohm and short circuit plots, possibly due to straw capcitiance and/or inductance. For the circuits, 0-50kHz shows ideal input impedance for the transformers.

The input impedance of transformers closely approximates the ideal impedance within the frequency range of 200 Hz to 10 kHz. The load impedance plays a vital role in influencing the transformer's input impedance, as it is directly dependent on the load impedance. Now, let's explore the input impedance observed at the secondary side of the transformer.

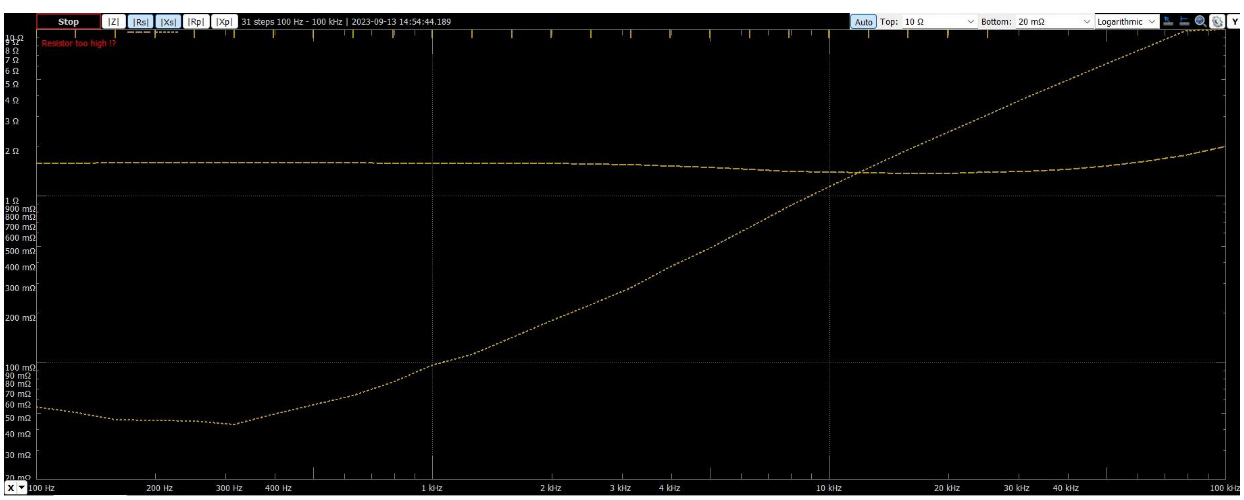


Figure 5.0 Input Impedance Frequency Sweep (Shorted Load)

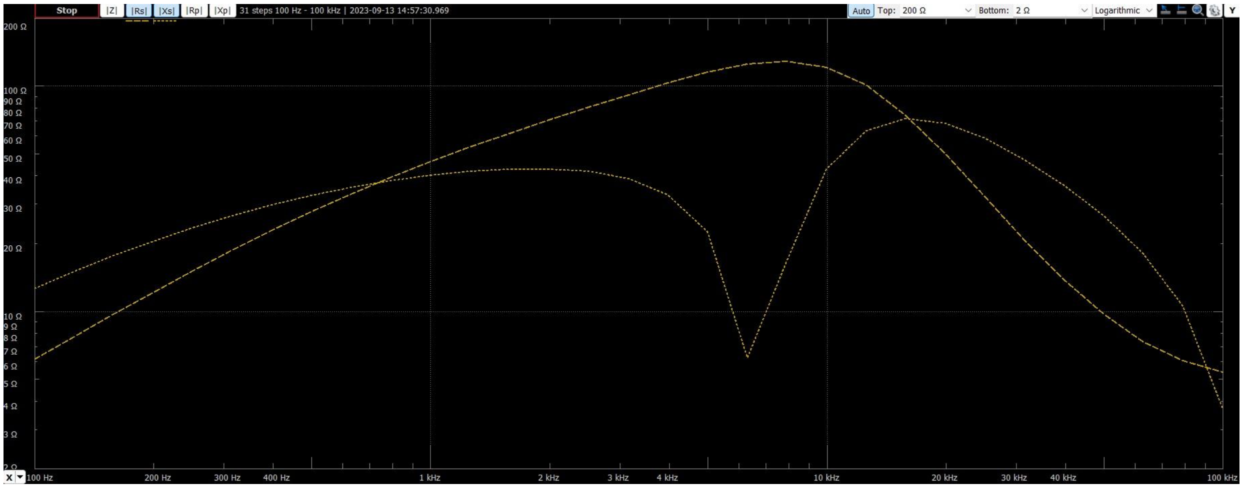


Figure 5.1 Input Impedance Frequency Sweep (47k Ohm Load)

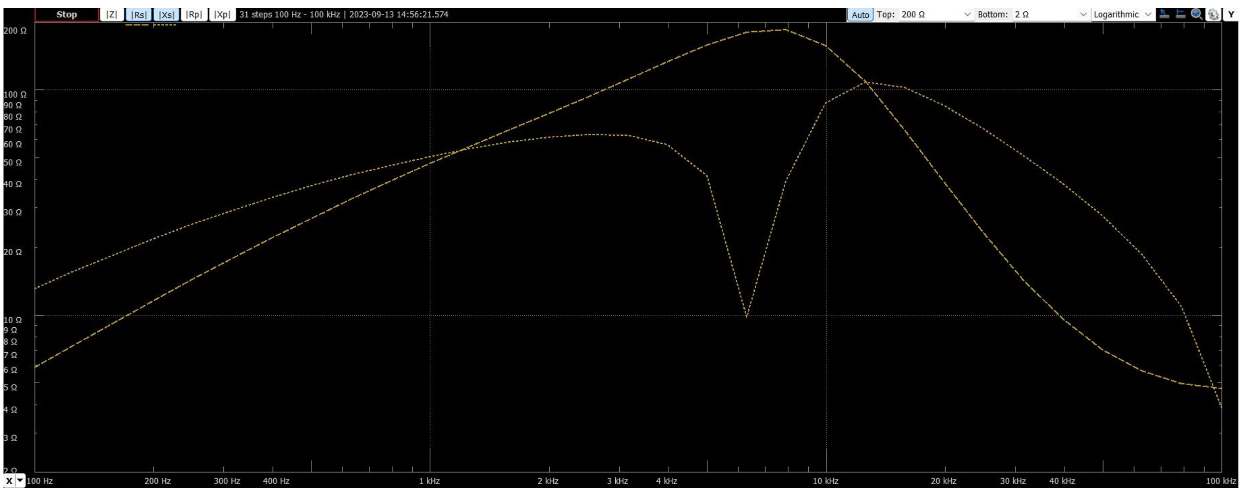


Figure 5.1 Input Impedance Frequency Sweep (1M Ohm Load)

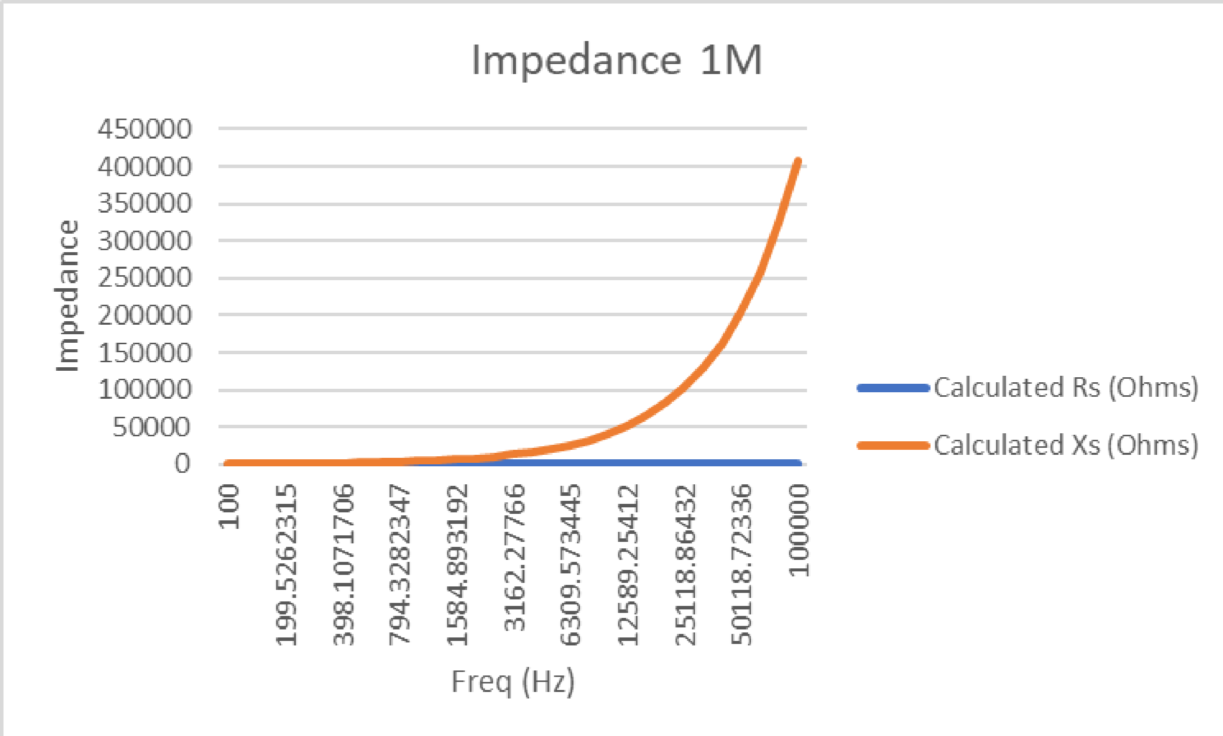


Figure 5.5 Secondary Input Impedance Calculations (1M ohm)

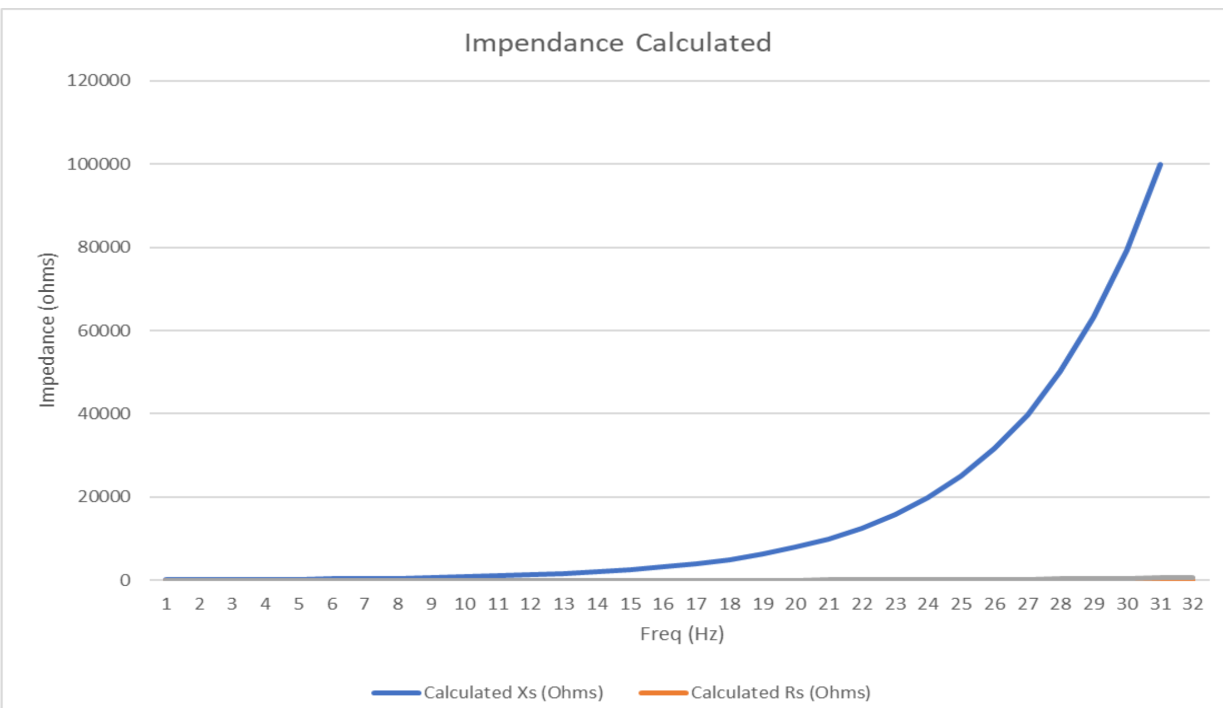


Figure 5.6 Input Impedance Calculations (Shorted Load)

Moving on, we will do power calculations to figure out the efficiency for our transformers across varying load impedances (10, 5, 1, and 0.5 Ohms.)

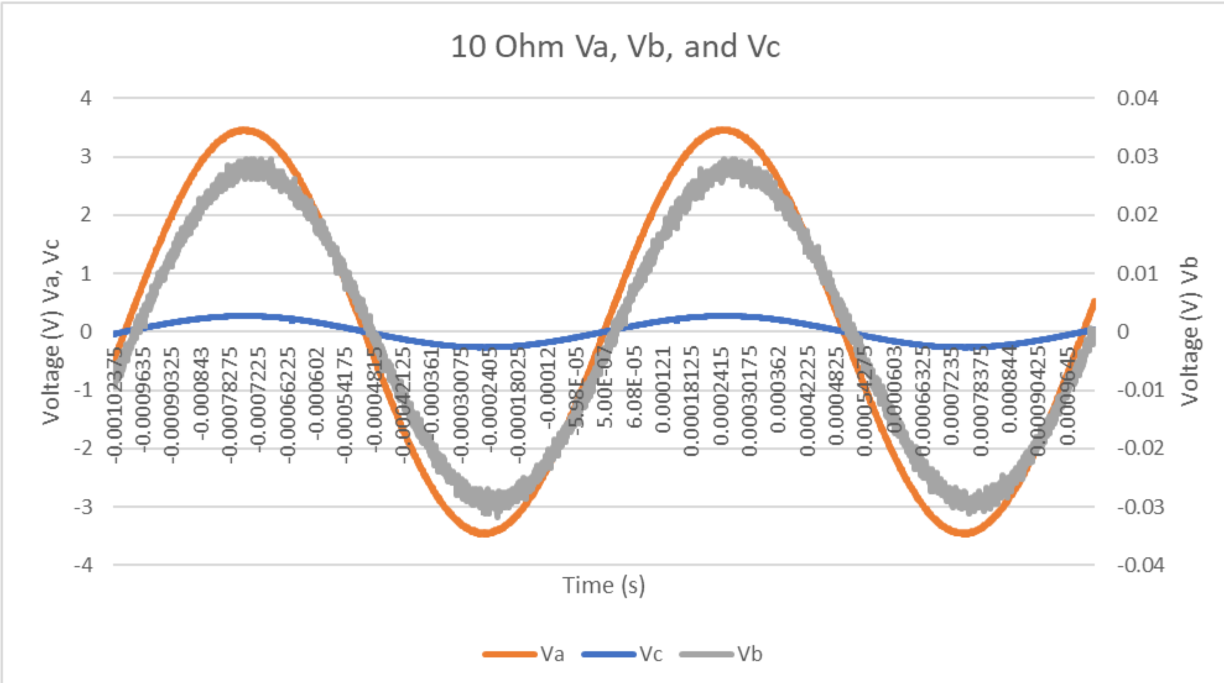


Figure 6.0 Power Waveforms (Va, Vb, Vb - 10 Ohm Load - Phase shift = 7.45 degrees)

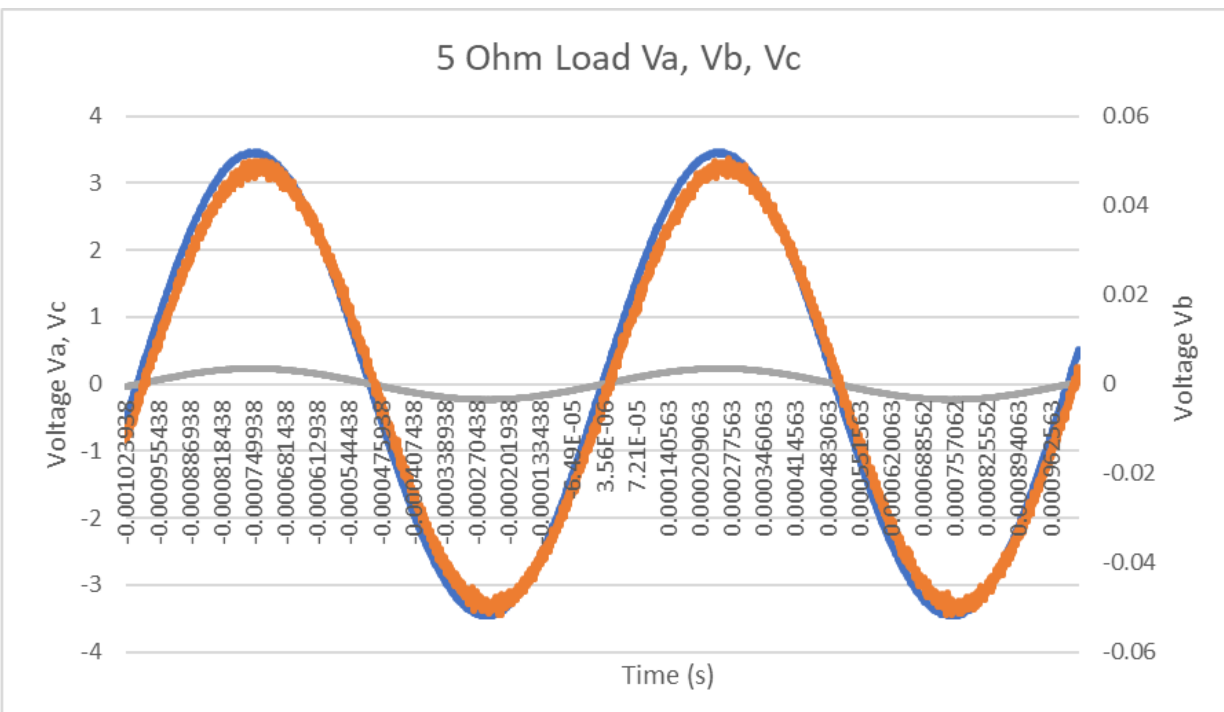


Figure 6.1 Power Waveformms (Va, Vb, Vc - 5 Ohm Load Phase shift = 3.9825 degrees

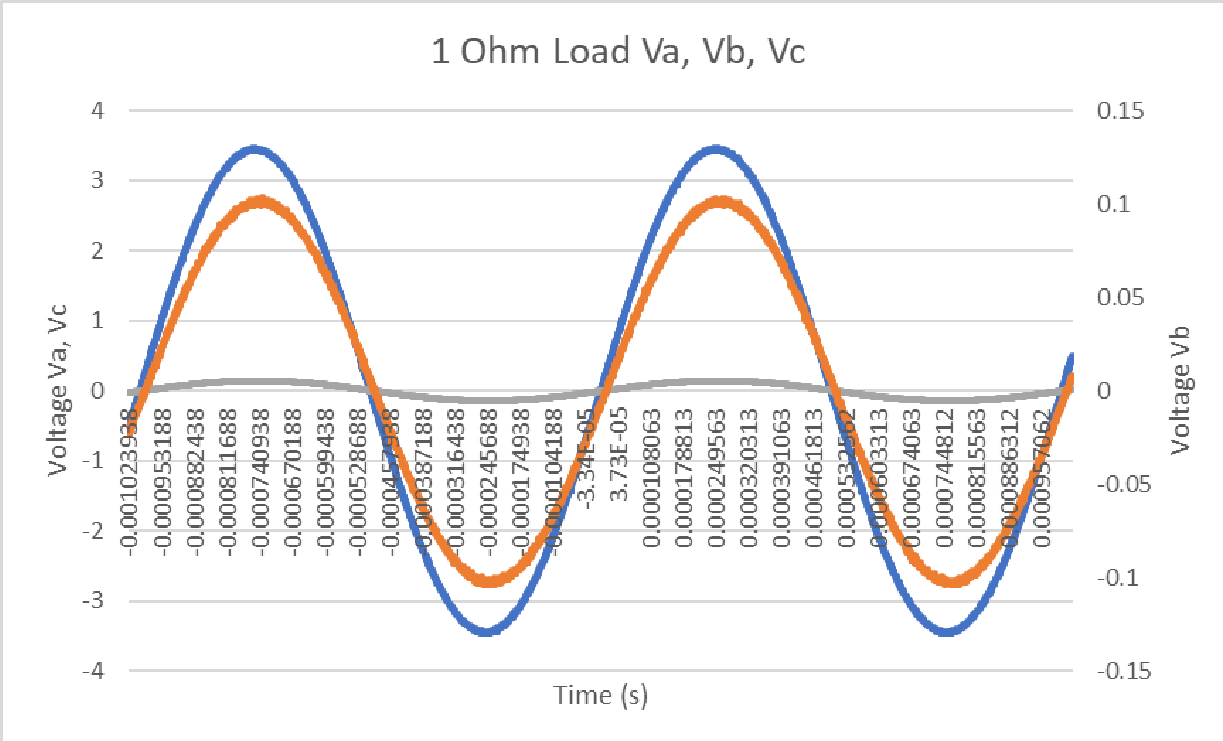


Figure 6.2 Power Waveforms (Va, Vb, Vc - 1 Ohm Load - Phase shift = 1.08 degrees)
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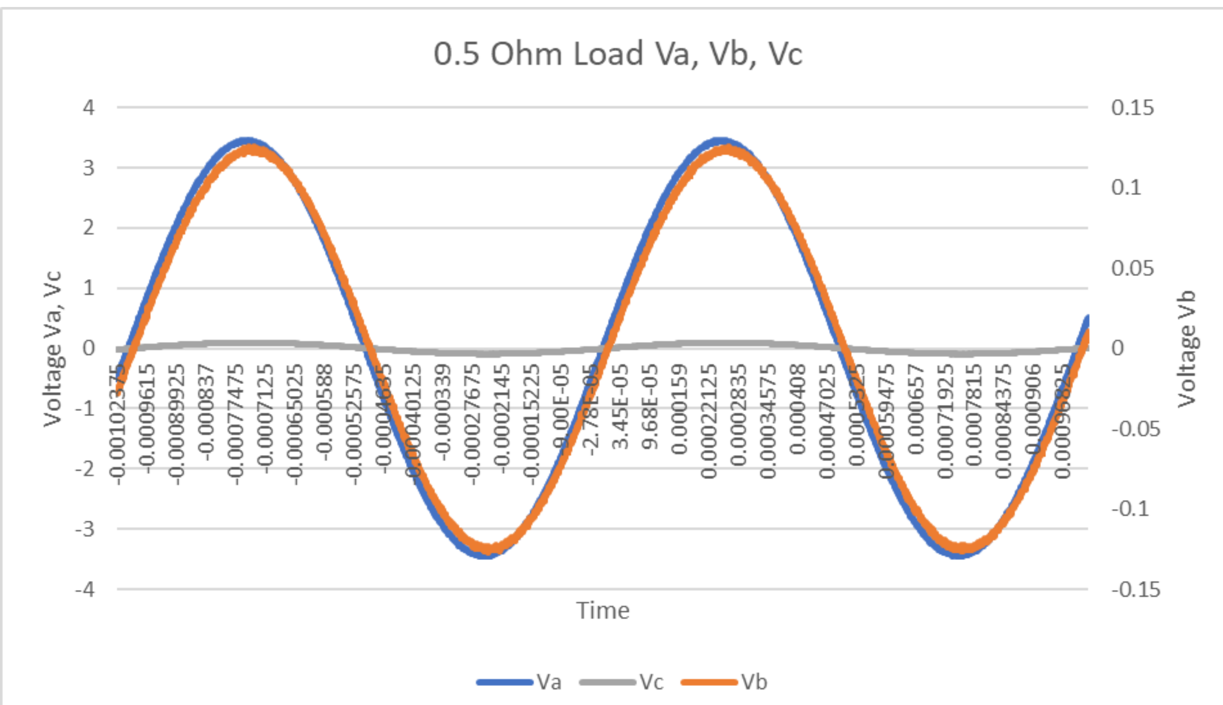

Figure 6.3 Power Waveforms (Va, Vb, Vc; 0.5 Ohm Load. Phase shift = 3.42 degrees)

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Now, we will calculate the power provided to the primary of the transformer.

For the 0.5 ohm load, we get approximately 61.23 + 6.8j mW of power to the primary
For the 1 ohm load, we get approximately 61.76 + 6.9j mW of power to the primary.
For the 5 ohm load, we get approximately 43.07 - 3.19j mW power to the primary.
For the 10 ohm load, we get approximately 33.48 - 3.34j mW power to the primary.

Here, we will calculate the power to each load.
For the 10 ohm load, we get approximately 7.265 mW.
For the 5 ohm load, we get approximately 10.9 mW.
For the 1 ohm load, we get approximately 21.1 mW.
For the 0.5 ohm laid, we get approximately 16.5 mW.

With the equation (= Load power / (Primary + AD2 power)),

Our power ratio is the following for all the loads.
Power ratio (½ ohm load) = 26.78%
Power ratio (1 ohm load) = 33.95%
Power ratio (5 ohm load) = 25.24%
Power ratio (10 ohm load) = 21.59%

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Conclusion

Our lab experiment went well because we got the right voltage measurements from the op amp circuit. We checked these values using a simple equation to find the output voltage. During the lab, I learned how to make a voltage amplifier with an op amp and how to create calibration curves. This experience taught me a lot about op amp-based amplification and how to make precise measurements using calibration curves, which are important in science and engineering for accurate data analysis and instrument calibration.