Constructor University Bremen

Natural Science Laboratory
Electrical Engineering Module I

Fall Semester 2024

Lab Experiment 4 – Two – Port Networks

Appendix Experiment 3 – Wheatstone Bridge

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Place of execution	: Teaching Lab 53
Date of execution	: March. 14, 2024

1 Introduction

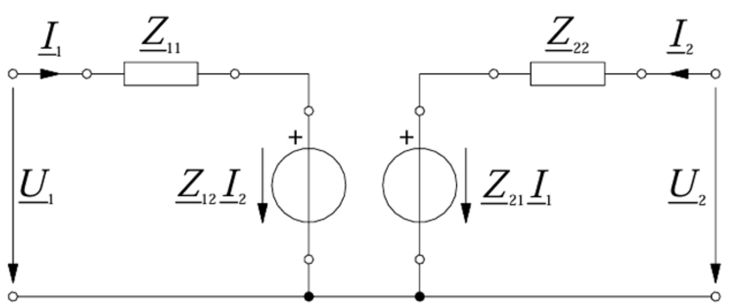
This experiment aims to provide a comprehensive understanding of the properties and behavior of selected two-port networks. The primary objective of this report is to explore the fundamental principles of voltage-driven two-port networks under both DC and AC conditions. By analyzing different configurations, including parallel, series, and cascade connections, the report seeks to establish a clear understanding of how these networks function.

A port is defined as a pair of terminals that allow current to flow in and out of a circuit. Basic circuit components such as resistors, capacitors, and inductors, which have only two terminals, form one-port networks. In contrast, a two-port network consists of an electrical system with distinct input and output ports, ensuring that the current entering one terminal of a port exits through the other, maintaining a net current of zero at each port. Through theoretical analysis and experimental observations, this report aims to highlight the key characteristics and practical applications of two-port networks.

2 Theory

Throughout this experiment, three different types of two-port networks were examined.

a) Two – Port Impedance Network

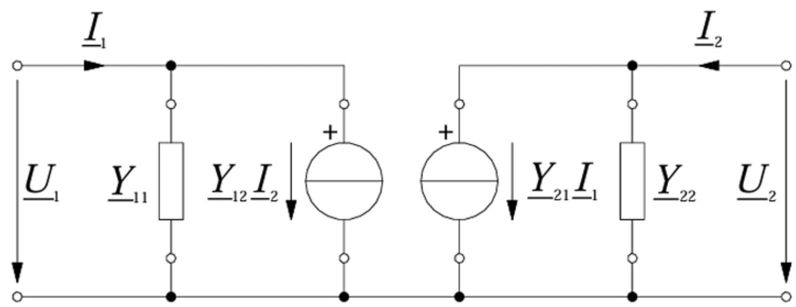


Where, Z parameters are measured using following formulas,

$$Z_{11} = \frac{V_1}{I_1}\bigg|_{I_2=0} \quad Z_{12} = \frac{V_1}{I_2}\bigg|_{I_1=0} \quad Z_{21} = \frac{V_2}{I_1}\bigg|_{I_2=0} \quad Z_{22} = \frac{V_2}{I_2}\bigg|_{I_1=0} \quad (eq. 1)$$

$$V_1 = Z_{11}I_1 + Z_{12}I_2$$
$$V_2 = Z_{21}I_1 + Z_{22}I_2$$

b) Two – Port Admittance Network

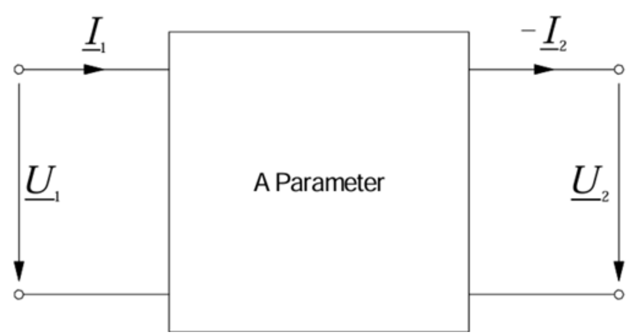


Where, Y parameters are measured using following formulas,

$$Y_{11} = \left.\frac{I_1}{V_1}\right|_{V_2=0} \quad Y_{12} = \left.\frac{I_1}{V_2}\right|_{V_1=0} \quad Y_{21} = \left.\frac{I_2}{V_1}\right|_{V_2=0} \quad Y_{22} = \left.\frac{I_2}{V_2}\right|_{V_1=0} \quad (eq. 2)$$

$$I_1 = Y_{11}V_1 + Y_{12}V_2$$
$$I_2 = Y_{21}V_1 + Y_{22}V_2$$

c) Two – Port Transmission ABCD – parameter Network



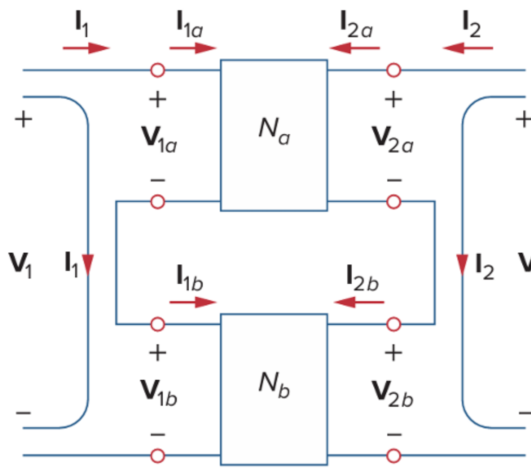
Where, Y parameters are measured using following formulas,

$$A = \left.\frac{V_1}{V_2}\right|_{I_2=0} \quad B = \left.\frac{V_1}{-I_2}\right|_{V_2=0} \quad C = \left.\frac{I_1}{V_2}\right|_{I_2=0} \quad D = \left.\frac{I_1}{-I_2}\right|_{V_2=0}$$

$$V_1 = AV_2 + B(-I_2)$$
$$I_1 = CV_2 + D(-I_{2)}$$

There are several combinations where two port networks can be connected to each other such as: series, parallel and cascade connections.

a) Series Connection

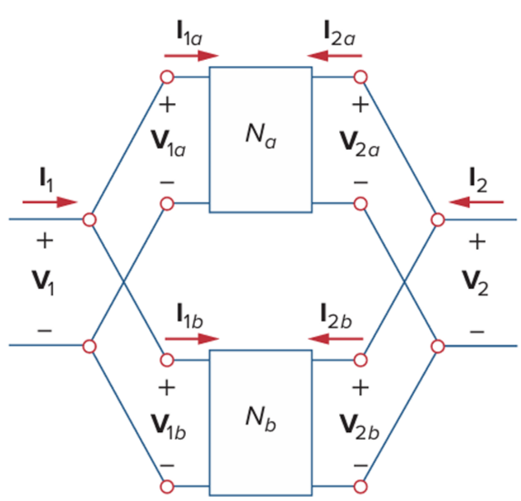


$$\begin{bmatrix} Z_{11} & Z_{12} \\ Z_{21} & Z_{22} \end{bmatrix} = \begin{bmatrix} Z_{11a} + Z_{11b} & Z_{12a} + Z_{12b} \\ Z_{21a} + Z_{21b} & Z_{22a} + Z_{22b} \end{bmatrix}$$

$$[Z] = [Z_a] + [Z_b]$$

When two two-port networks are connected in series, the total voltage across the combination is the sum of the individual voltages of each network, while the current remains the same throughout both networks. This is a fundamental property of series circuits. Likewise, the impedance parameters (Z-parameters) of the individual two-port networks add up.

b) Parallel Connection

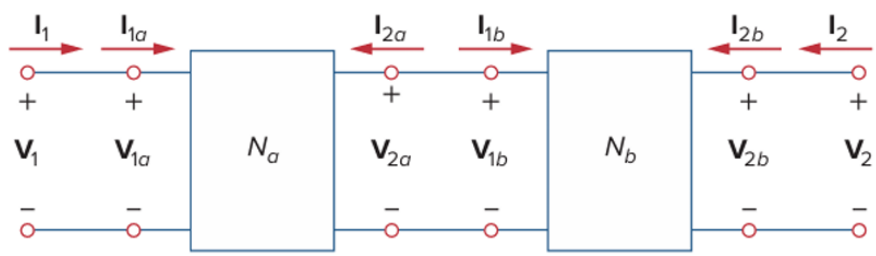


$$\begin{bmatrix} Y_{11} & Y_{12} \\ Y_{21} & Y_{22} \end{bmatrix} = \begin{bmatrix} Y_{11a} + Y_{11b} & Y_{12a} + Y_{12b} \\ Y_{21a} + Y_{21b} & Y_{22a} + Y_{22b} \end{bmatrix}$$

$$[Y] = [Y_a] + [Y_b]$$

When two two-port networks are connected in parallel, the total current flowing through the combination is the sum of the individual currents in each network, while the voltage across both remains the same. This characteristic follows the fundamental principles of parallel circuits. Similarly, the admittance parameters (Y-parameters) of the two networks add up.

c) Cascade Connection



$$\begin{bmatrix} A & B \\ C & D \end{bmatrix} = \begin{bmatrix} A_a & B_a \\ C_a & D_a \end{bmatrix} * \begin{bmatrix} A_b & B_b \\ C_b & D_b \end{bmatrix}$$

$$[T] = [T_a] * [T_b]$$

3 Experimental Part 1 – Two-Port Z/Y Network

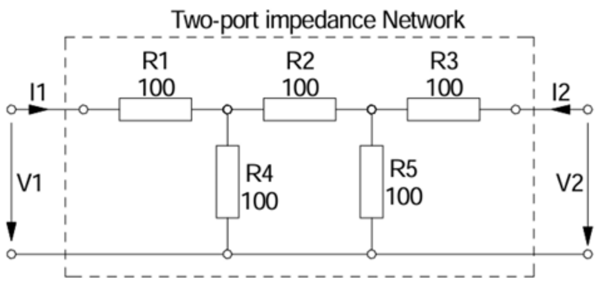
Workbench No.8

Used tools and Instruments:

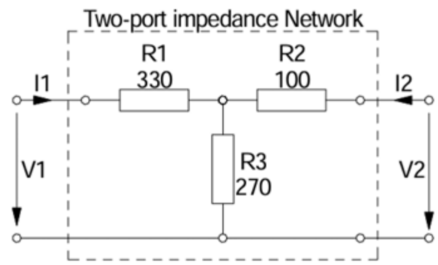
- Signal Generator
- TENMA Multimeter
- BNC Cable, Banana Connector
- Oscilloscope
- 5 x 100 Ohm and 1 x10 Ohm Resistors
- 2 x 1uF Capacitor
- 1 x 1000 Ohm Resistor
- 330 Ohm and 270 Ohm Resistors

The objective of Part 1 is to determine Z and Y parameters of the networks experimentally.

Test Circuit



Circuit 1



Circuit 2

Description of the measurements

To analyze the impedance parameters (Z-parameters) of the two-port network, currents I_1 and I_2 were opened one at a time by disconnecting the corresponding connections. For each case, the voltages V_1 and V_2 were measured using a TENMA multimeter. Additionally, the total impedance was calculated each time a current source was opened. Using Ohm's Law and the relevant equations, the corresponding current values and Z-parameters were determined.

When $I_2 = 0$ and I_1 is active, the total impedance of the system was measured as Z_T = 166.7 Ω. To calculate Z_{12} parameter, we measured $V_1 = 1.0181\ V$, then we measured the voltage across R_3 resistor ($V_{R_3} = 3.052\ V$) and using Ohm's law we determined $I_2 = 0.03052\ A$.

Similarly, when $I_1 = 0$ and I_2 is active the total impedance of the system was measured as Z_T = 166.7 Ω. To calculate Z_{21} parameter, we measured $V_2 = 1.0159\ V$, then we measured the voltage across R_1 resistor ($V_{R_1} = 3.047\ V$) and using Ohm's law we determined $I_1 = 0.03047\ A$.

According (eq.1) all Z parameters were calculated:

Z-11(Ω)	Z-12(Ω)	Z-21(Ω)	Z-22(Ω)
166.77	33.35845	33.34099	166.69

Table 1. Measured Z parameters for Circuit 1

To determine the admittance parameters (Y-parameters) for Circuit 2, voltages V_1 and V_2 were short-circuited one at a time by connecting a wire between the respective points in the circuit. In each case, the total impedance was calculated, and the corresponding voltage V_1 when $V_2 = 0$, and V_2 when $V_1 = 0$ was measured using the TENMA multimeter. By applying Ohm's Law and the relevant equations, the currents were determined, allowing for the calculation of the Y-parameters.

To calculate Y_{11} and Y_{22} we first measured the impedances Z_{11} and Z_{22} and then took the inverse of them.

When V_1 is shorted the voltage across $V_2 = 5.062\,V$. To calculate Y_{12} parameter, we measured $V_{R_1} = -3.024\,V$, then using Ohm's law we determined $I_1 = -0.00916\,A$.

Similarly, when V_2 is shorted the voltage across $V_1 = 5.065\,V$. To calculate Y_{21} parameter, we measured $V_{R_2} = -0.912\,V$, then using Ohm's law we determined $I_2 = -0.00912\,A$.

According (eq.2) all Y parameters were calculated:

Y-11(s)	Y-12(s)	Y-21(s)	Y-22(s)
0.002482	-0.00181	-0.0018	0.004024

Table 2. Measured Y parameters for Circuit 2

Finally, with a voltage supply of $V_1 = 5V$ and a load resistance of $R_L = 1k\Omega$, the values of V_1, V_2 , I_1, and I_2 were determined. Instead of measuring the currents directly, the voltages were recorded and then used to calculate the corresponding currents using Ohm's Law.

V1(V)	V2(V)	I1(A)	I2(A)
5.066	0.875	0.03054	-0.00085

Table 3. Measured Voltages and currents for Circuit 1

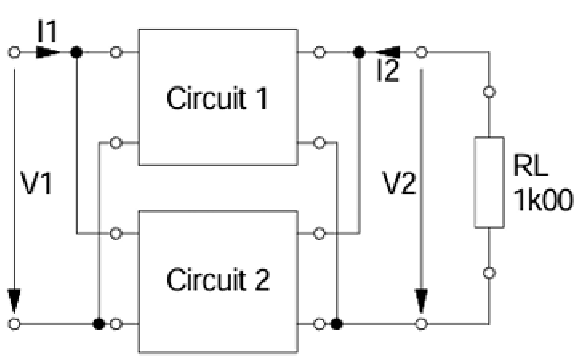
V1(V)	V2(V)	I1(A)	I2(A)
5.068	1.819	0.009291	-0.0018

Table 4. Measured Voltages and currents for Circuit 2

4 Experimental Part 2 – Interconnection f Two-Port Networks

The objective of Part 2 is to illustrate the behavior of two-port networks when connected in parallel. To achieve this, the circuits analyzed in Part 1 were reconfigured into a parallel arrangement, as depicted in the corresponding figure.

Test Circuit



To calculate Z_{11} and Z_{22} the total impedance was measured when $I_2$and $I_1$was zero respectively. Since the given circuits were connected in parallel, the total input current I_1 was the sum of the individual currents flowing through each circuit. Mathematically, this relationship is expressed as: $I_1 = I_a + I_b$ where I_a and I_b represent the currents flowing through Circuit 1 and Circuit 2, respectively.

To measure Z_{12}, first we measured $V_1 = 1.7659\ V$, then currents flowing through Circuit 1 ($I_{2a} = 0.02939\ A$) and Circuit 2 ($I_{2b} = 0.01716\ A$) and we determined $I_2 = 0.04655\ A$
Same for Z_{22}, we measured $V_2 = 1.503\ V$, then currents flowing through Circuit 1 ($I_{1a} = 0.02976\ A$) and Circuit 2 ($I_{1b} = 0.0098424\ A$) using Ohm's law and then we determined $I_1 = 0.0396\ A$.

According (eq.1) all Z parameters were calculated:

Z-11(Ω)	Z-12(Ω)	Z-21(Ω)	Z-22(Ω)
128.2	37.93555	37.95222	108.84

Table 5. Measured Z parameters for Parallel Combination

Finally, with a voltage supply of $V_1 = 5V$ and a load resistance of $R_L = 1k\Omega$, the values of V_1, V_2, I_1, and I_2 were determined. Like Part 1, instead of measuring the currents directly, the voltages were recorded and then used to calculate the corresponding currents using Ohm's Law.

V_1 (V)	V_2 (V)	I_1 (A)	I_2 (A)
5.065	1.37	0.040011	-0.00136

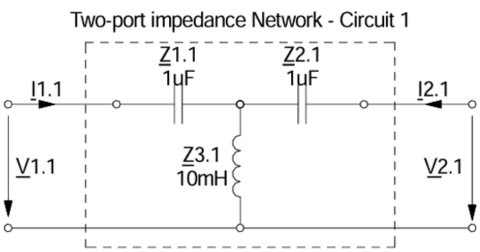
Table 6. Measured Voltages and Currents for Parallel Combination

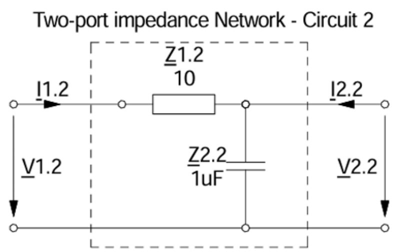
5 Experimental Part 3 – Complex Two-Port Networks / Cascading

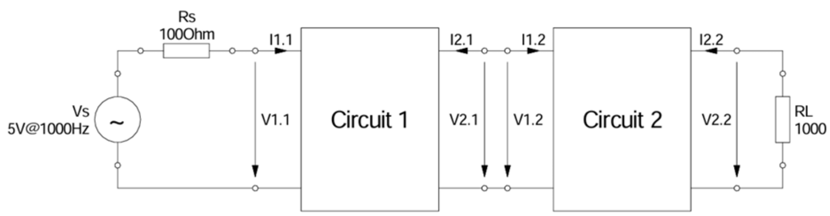
The objective of Part 3 of the experiment was to explore the cascading of complex two-port networks. In this section, the circuits were assembled on a breadboard and connected in a cascaded configuration, as illustrated in the corresponding figure.

A voltage supply of $V_s = 5V_{PP}$ at a frequency of 1000Hz was applied to analyze the behavior of the cascaded network.

Test Circuit







Using $v_{1.1}$ as the reference, the voltage supply v_s and $v_{1.1}$ were measured at Circuit 1 using the oscilloscope and multimeter. Similarly, $v_{2.2}$ was measured using the oscilloscope and the current $i_{2.2}$ were measured using the TENMA multimeter at Circuit 2. The measured values were then organized and presented in Table for further analysis.

V_s(V)	V_1.1(V)	I_1.1(A)	V_2.2(V)	I_2.2(A)
7.5∠55	4.8∠0	0.028∠87.6	2.4∠169	-0.0024∠172

Table 7. Measured Voltages and Currents for
Part 3 – Phasor Form

The impedances of each component in the circuit were measured using an RLC meter.

Element	Value	Resistance (Ω)	Reactance (Ω)
R_1.2	10 Ω	10.078	j0.2*10^$^{-3}$
R_s	100 Ω	99.91	j0.25*10^{-3}
R_L	1000 Ω	990	j1.11*10^{-3}
C_z1.1	1 miuF	0.55434	-j150.8
C_z2.1	1 miuF	1.13	-j169.89
C_z2.2	1 miuF	0.5527	-j149.19
L_z3.1	10 mH	4.4468	j65.254

Table 8. Impedance Values from RLC Meter

6 Evaluation Part 1 - Two-Port Z/Y Network

Calculating the Z parameters of circuit 1 and 2:
Circuit 1 - $I_2 = 0$

$$R_{total} = (100 + 100)||(100) + 100 = 166.67\ \Omega$$

$$V_1 = I_1 * R_{total} \ \rightarrow \ Z_{11} = \frac{V_1}{I_1} = R_{total} = 166.67\ \Omega$$

Using current divider formula, we can calculate the current passing through R_5:

$$I_{R_5} = \frac{100}{300} * I_1 = \frac{1}{3} * I_3 \ \rightarrow \ Z_{21} = \frac{V_2}{I_1} = \frac{100}{3} = 33.3\ \Omega$$

By symmetry of the circuit, we can say that when $I_2 = 0$

$$Z_{12} = 33.3\ \Omega \ and \ Z_{22} = 166.67\ \Omega$$

Therefore, we have all Z parameter for circuit 1

$$Z_1 = \begin{bmatrix} 166.67 & 33.3 \\ 33.3 & 166.67 \end{bmatrix}$$

Circuit 2 - $I_2 = 0$

$$R_{total} = (330 + 270) = 600\ \Omega$$

$$V_1 = I_1 * R_{total} \ \rightarrow \ Z_{11} = \frac{V_1}{I_1} = R_{total} = 600\ \Omega$$

$$V_2 = 270 * I_1 \ \rightarrow \ Z_{21} = \frac{V_2}{I_2} = 270\ \Omega$$

When $I_1 = 0$

$$R_{total} = (270 + 100) = 370\ \Omega$$

$$V_2 = I_2 * R_{total} \ \rightarrow \ Z_{22} = \frac{V_2}{I_2} = R_{total} = 370\ \Omega$$

$$V_1 = 270 * I_2 \ \rightarrow \ Z_{12} = \frac{V_1}{I_2} = 270\ \Omega$$

Therefore, we have all Z parameter for circuit 2

$$Z_2 = \begin{bmatrix} 600 & 270 \\ 270 & 370 \end{bmatrix}$$

To calculate Y parameters the following formula was used:

$$Y = Z^{-1}$$

We used MATLAB to calculate inverse of $Z_1$and Z_2:

$$Y_1 = \begin{bmatrix} 0.006235 & -0.001250 \\ -0.001250 & 0.006235 \end{bmatrix}$$

$$Y_2 = \begin{bmatrix} 0.00248 & -0.00181 \\ -0.00181 & 0.004024 \end{bmatrix}$$

When comparing the measured values with the calculated ones, both the Z-parameters and Y-parameters showed a strong correlation, indicating the accuracy of the theoretical model. However, slight discrepancies were observed, which is expected due to factors such as measurement tolerances, component imperfections, and minor experimental uncertainties.

Parameter	Calculated(Ω)	Measured (Ω)
Z_11	166.77	166.67
Z_12	33.35845	33.33
Z_21	33.34099	33.33
Z_22	166.69	166.67
Y_11	0.002482	0.00248
Y_12	-0.00181	-0.00181
Y_21	-0.0018	-0.00181
Y_22	0.004024	0.004024

Table 9. Comparison between calculated and measured values

To calculate values of V_1, V_2, I_1, I_2 the following formulas were used:

$$V_1 = Z_{11}I_1 + Z_{12}I_2 \qquad V_2 = Z_{21}I_1 + Z_{22}I_2$$

$$I_1 = Y_{11}V_1 + Y_{12}V_2 \qquad I_2 = Y_{21}V_1 + Y_{22}V_2$$

For Circuit 1

$$V_1 = 166.67 * 0.03054 + 33.33 * (-0.00085) = 5.09 - 0.02833 = \mathbf{5.061\ V}$$

$$V_2 = 33.33 * 0.03054 + 166.67 * (-0.00085) = 1.0179 - 0.1416 = \mathbf{0.876\ V}$$

$$5.061 = 166.67 * I_1 + 33.33 * I_2$$

$$0.876 = 33.33 * I_1 + 166.67 * I_2$$

After solving these equations:

$$I_1 = \mathbf{0.0304\ A}$$

$$I_2 = \mathbf{-0.000867\ A}$$

For Circuit 2

$$I_1 = 0.00248 * 5.068 + (-0.00181) * 1.819 = 0.01256 - 0.00329 = \mathbf{0.00927 A}$$

$$I_2 = (-0.0018) * 5.068 + 0.004024 * 1.819 = -0.00912 + 0.00732 = \mathbf{0.0018\ A}$$

$$0.00929 = 0.00248 * V_1 + (-0.0018) * V_2$$

$$-0.0018 = (-0.0018) * V_1 + 0.004024 * V_2$$

After solving these equations:

$$V_1 = \mathbf{5.0413\ V}$$

$$V_2 = \mathbf{1.8053\ V}$$

Since the calculated values closely match the measured values, we can conclude that the results are accurate. However, minor discrepancies are inevitable due to various sources of error. One potential source is instrumental error, as the TENMA multimeter used for measurements has an accuracy tolerance of 1%, which could have contributed to slight deviations. Additionally, component tolerances, including variations in resistor values and imperfections in the breadboard connections, may have introduced small measurement errors.

7 Evaluation Part 2 - Interconnection f Two-Port Networks

We want to determine combined Y parameter of the parallel circuit, where we know that:

$$[Y] = [Y_a] + [Y_b]$$

$$Y_1 = \begin{bmatrix} 0.006235 & -0.001250 \\ -0.001250 & 0.006235 \end{bmatrix}$$

$$Y_2 = \begin{bmatrix} 0.00248 & -0.00181 \\ -0.00181 & 0.004024 \end{bmatrix}$$

$$[Y_T] = [Y_1] + [Y_2] = \begin{bmatrix} 0.006235 & -0.001250 \\ -0.001250 & 0.006235 \end{bmatrix} + \begin{bmatrix} 0.00248 & -0.00181 \\ -0.00181 & 0.004024 \end{bmatrix} =$$

$$= \begin{bmatrix} 0.008715 & -0.00306 \\ -0.00306 & 0.010259 \end{bmatrix}$$

Using MATLAB we get the inverse,

$$Z_T = \begin{bmatrix} 128.1677 & 38.2292 \\ 38.2292 & 108.8782 \end{bmatrix} - Theoretical$$

The measured value for Z_T was:

$$Z_T = \begin{bmatrix} 128.2 & 37.9355 \\ 37.9522 & 108.84 \end{bmatrix} - Experimental$$

As observed, the calculated Z-parameters and the measured Z-parameters are comparable, but a noticeable difference exists between them. This discrepancy is likely since the measured Z and Y parameters, rather than the theoretical values from Part 1 of the experiment, were used in calculating the Z-parameters of the parallel circuit.

To verify the measured values for V_1 and V_2

$$V_1 = 128.167 * 0.040011 + 37.9355 * (-0.00136) = 5.14 - 0.0516 = \mathbf{5.0884\ V}$$

$$V_2 = 37.9522 * 0.040011 + 108.84 * (-0.00136) = 1.5185 - 0.1480 = \mathbf{1.37\ V}$$

The calculated values were found to be nearly identical to the measured values, with only minor differences. These discrepancies can be attributed to measurement errors, particularly from the TENMA multimeter, which has an inherent accuracy tolerance. Another possible source of error comes from the circuit components themselves—resistors may not precisely match their theoretical values due to manufacturing tolerances. However, since the measured values remain consistent with the theoretical expectations, they can be considered valid.

For a series combination of two-port networks, it is generally possible to determine the overall Z-parameters by summing the individual Z-parameters of each network, as expressed by:

$$[Z]=[Z_a]+[Z_b]$$

However, this approach is not always applicable. Certain conditions, such as short circuits in the connections between two ports, can disrupt this relationship, leading to unexpected behavior. In such cases, the circuit may not behave as a simple series combination, and direct application of the equation would not accurately determine the Z-parameters. Similarly, in this experiment, if the two two-ports were connected in series, a short circuit bypass might have prevented the expected calculation of the overall Z-parameters, highlighting the importance of carefully considering circuit conditions in practical applications.

8 Evaluation Part 3 - Complex Two-Port Networks / Cascading

Calculating the Z parameters for Circuit 1

When $I_2 = 0$

$$Z_{total} = C_1 + L = 5.0527 - j102.5224$$

$$V_1 = I_1 * Z_{total} = (5.0527 - j102.5224) * I_2 \;\rightarrow\; Z_{11} = \frac{V_1}{I_1} = 5.0527 - j102.5224$$

$$V_2 = (4.4397 + j65.3576) * I_1 \;\rightarrow\; Z_{21} = \frac{V_2}{I_1} = 4.4397 + j65.3576$$

When $I_1 = 0$

$$Z_{total} = C_2 + L = 5.5694 - j84.7824$$

$$V_2 = I_2 * Z_{total} = (5.5694 - j84.7824) * I_2 \;\rightarrow\; Z_{22} = \frac{V_2}{I_2} = 5.5694 - j84.7824$$

$$V_1 = (4.4397 + j65.3576) * I_2 \;\rightarrow\; Z_{12} = \frac{V_1}{I_2} = 4.4397 + j65.3576$$

Therefore,

$$Z_1 = \begin{bmatrix} 5.0527 - j102.5224 & 4.4397 + j65.3576 \\ 4.4397 + j65.3576 & 5.5694 - j84.7824 \end{bmatrix}$$

Calculating the Z parameters for Circuit 2

When $I_2 = 0$

$$Z_{total} = C_3 + L = 10.581 - j167.88$$

$$V_1 = I_1 * Z_{total} = (10.581 - j167.88) * I_1 \rightarrow Z_{11} = \frac{V_1}{I_1} = 10.581 - j167.88$$

$$V_2 = (0.617 - j167.88) * I_1 \rightarrow Z_{21} = \frac{V_2}{I_1} = 0.617 - j167.88$$

When $I_1 = 0$

$$Z_{total} = C_3 = 0.617 - j167.88$$

$$V_2 = I_2 * Z_{total} = (0.617 - j167.88) * I_2 \rightarrow Z_{22} = \frac{V_2}{I_2} = 0.617 - j167.88$$

$$V_1 = (0.617 - j167.88) * I_2 \rightarrow Z_{12} = \frac{V_1}{I_2} = 0.617 - j167.88$$

Therefor,

$$Z_2 = \begin{bmatrix} 10.581 - j167.88 & 0.617 - j167.88 \\ 0.617 - j167.88 & 0.617 - j167.88 \end{bmatrix}$$

To measure the Cascaded ABCD parameters, the following formulas were used,

$$T = \begin{bmatrix} \frac{Z_{11}}{Z_{21}} & \frac{\Delta Z}{Z_{21}} \\ \frac{1}{Z_{21}} & \frac{Z_{22}}{Z_{21}} \end{bmatrix}$$

$$[T] = [T_a][T_b]$$

Using MATLAB, we determined T_1 and T_2

$$T_1 = \begin{bmatrix} -1.5562 - j0.1831 & -28.6237 + j65.561 \\ 0.001034 - j0.0152 & -1.2855 - j0.17253 \end{bmatrix}$$

$$T_2 = \begin{bmatrix} 1.0002 - j0.05935 & 9.9640 + j0.000 \\ 0.00002 - j0.005957 & 1 \end{bmatrix}$$

$$T = \begin{bmatrix} -1.5562 - j0.1831 & -28.6237 + j65.561 \\ 0.001034 - j0.0152 & -1.2855 - j0.17253 \end{bmatrix} *$$

$$* \begin{bmatrix} 1.0002 - j0.05935 & 9.9640 + j0.000 \\ 0.00002 - j0.005957 & 1 \end{bmatrix} =$$

$$= \begin{bmatrix} -1.9368 - j0.4445 & -44.130 + j63.738 \\ 0.002938 - j0.02283 & -1.27518 - j0.3243 \end{bmatrix}$$

To verify the measured V_1 and V_2 values for cascaded circuit, the following formula were used:

$$V_1 = A * V_2 + B * (-I_2)$$

$$I_1 = C * V_2 + D * (-I_2)$$

We used the determined ABCD parameters and measured V_2 and I_2

$$V_2 = 2.4\angle 169 = 1.916 - \mathrm{j}1.44\ \mathrm{V}$$
$$V_1 = (-1.9368 - j0.4445) * (1.916 - j1.44) + (-44.130 + j63.738) * \big(-(-0.0024)\big) =$$
$$= 4.460 - j2.0929\ V$$
$$V_1 = \mathbf{4.926\angle - 154.86\ V}$$

$$I_2 = (0.002938 + j0.02283) * (1.916 - j1.44) + (-1.27518 - j0.3243) * \big(-(-0.0024)\big) =$$
$$= 0.03544 + j0.0387\ A$$
$$I_1 = \mathbf{0.036\angle 47.52\ A}$$

The calculated values and the measured values were generally in good agreement; however, some differences were observed. These discrepancies could have arisen due to errors introduced during calculations or while taking measurements with the TENMA multimeter. Additionally, both the TENMA and the oscilloscope have inherent measurement tolerances that must be considered as potential sources of deviation.

9 Conclusion

In this experiment, various types of two-port networks were constructed and analyzed, including single two-port networks, parallel-connected two-port networks, and cascaded two-port networks. The behavior of each configuration was studied to understand how their parameters relate to each other.

From Part 1, it was observed that the Z-parameters of a two-port network are the inverse of its Y-parameters, demonstrating the fundamental relationship between impedance and admittance representations. In Part 2, the parallel connection of two-port networks confirmed that their Y-parameters simply add up, reinforcing the principle that admittance behaves additively in parallel circuits. Finally, in Part 3, it was concluded that for cascaded two-port networks, the overall ABCD parameters could be determined by multiplying the ABCD parameters of the individual networks, a key result in network analysis.

Throughout the experiment, the measured values aligned well with the theoretical predictions, validating the mathematical models used. However, minor discrepancies were observed due to instrumental errors, component tolerances, and calculation uncertainties. Despite these limitations, the experiment successfully demonstrated the key properties of two-port networks and provided valuable insights into their practical applications in circuit analysis.

10 References

- Lab Manual - http://uwp-raspi-lab.jacobs.jacobs
- Fundamental Of Electric Circuits – Sadiku
- https://testbook.com/electrical-engineering/two-port-network

11 Appendix

8.3.1

measured from elabo			
range	resistor name	Resistances (k ohm)	
200	R1	22.02	
20	R3	2.19	
20	R4	8.22	

step - 2 and 3	V_source (elabo) (V)	(mV) Tenma	R_decade (ohm	R_decade measured by elabo (range = 200) (k ohm)
	15	0.11	82440	82.6

8.4.2

after 5 min			
voltage(elabo) range(2) (V)		V_out(tenma)(mv)	
1.0033		-22	

after 10 min			
voltage(elabo) range(2) (V)		V_out(tenma)(mv)	
10.009		-245.21	

8.5.1

R1	0.9936
R2	0.9975
R3	0.994

C_1	0.9602 µF
R_P	51.137 kΩ
Y	6.0326 ms
theta	89.81

8.5.2

V_ab (elaborated)	R_adj	C_adj	phase difference CH1 - CH2
3.48	1020 ohms	24 nF	-2.16

R_padj	C_padj
1.0235 killo ohm	24.144 nF