AC Circuits Laboratory Lab # 5

The Thevenin Equivalent Circuit and Maximum Power Transfer

Lab Objectives

1. To predict the Thevenin Equivalent circuit that is equivalent to a more complex circuit at a given frequency.
2. To measure and record predicted circuit responses in the laboratory and compare these to the predicted and simulated responses from prelab.
3. To create documentation to demonstrate the equivalence of two circuits at a given frequency.
4. To demonstrate understanding of how a Thevenin circuit is equivalent to the original.
5. To demonstrate the effect of varying loads on an AC circuit with a focus on the power transferred to the load.

Pre-Laboratory Preparation

Prior to your scheduled laboratory meeting time the following items need to be completed. The pre-lab quiz will be based on this preparation. There is one lab note at the end of this document, read it before coming to lab.

1) Review this entire lab handout and develop an understanding of the prelab and lab activities. Using this understanding, create a data table using Excel. The Data table should have room to record load current $\mathbf{I_L}$ (magnitude AND angle) and load power, $\mathbf{P_L}$ for 2 different circuits (the original and the Thevenin equivalent) and 3 different load impedances $\mathbf{Z_{L1}}$, $\mathbf{Z_{L2}}$ and $\mathbf{Z_{L3}}$. You will be recording values pertaining to the original circuit (calculated and measured) and the Thevenin Equivalent circuit (calculated only) in this table. Be sure to leave room to record % error calculations for each measurement vs. prediction (original circuit only).
2) Study the circuit in Figure 1. On green engineering or quadrille lined paper, using $\mathbf{e_1}$ = 5Vp, calculate the open circuit voltage $\mathbf{V}_{ab\_oc}$ ($\mathbf{Z}_L$ removed), magnitude and phase angle. Calculate the Thevenin Equivalent impedance $\mathbf{Z_{TH}}$ for this circuit (again - magnitude **and** phase angle).
3) Based on the results of step 3, sketch the Thevenin Equivalent circuit for Figure 1 determined by calculation and label it properly.
4) Calculate the load impedance $\mathbf{Z_L}$, that would dissipate the maximum power, showing your work. This value will be called $\mathbf{Z_{L1}}$ in this lab.
5) Calculate and record $\mathbf{I_L}$ and $\mathbf{P_L}$ (the real power dissipated by $\mathbf{Z_L}$) for this load for both the original circuit and the Thevenin Equivalent circuit.
6) Repeat step 5 for $\mathbf{Z_{L2}}$ = 1000 Ω.
7) Repeat step 5 for $\mathbf{Z_{L3}}$ = 15 kΩ.
8) Capture and Simulate the circuit in figure 1. Use the transient analysis function to measure the open circuit voltage $\mathbf{V}_{ab\_oc}$ (magnitude and phase angle). Remember that an open circuit is simulated by a resistor of very large value (>1,000MΩ for example). Capture an image of the simulation (schematic and your output waveform) and embed it in a Word document. Label these images properly and neatly.
9) Replace the open circuit from step 8 with a resistor of very small value for $\mathbf{Z_L}$ (1Ω or so). Simulate, capture and embed the image as in step 8, recording the (almost) short-circuit current (including magnitude and phase angle) through the sample resistor.
10) Calculate and record in the same Word document, the Thevenin Equivalent Impedance using the information determined through simulation in steps 8 and 9. Remember: $\mathbf{V_{OC}/I_{SC} = Z_{TH}}$
11) Based on the results from steps 8 through 10, sketch the Thevenin Equivalent circuit for Figure 1 determined by simulation and label it properly.

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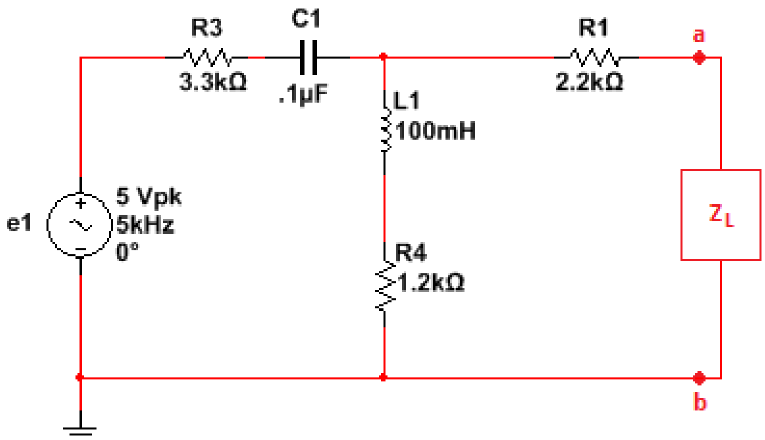
Figure 1:



AC Circuits Lab Procedure: Work with your lab partners and make sure you know your assigned roles

1) Build the original circuit shown in Figure 1 with terminals a and b open-circuit. Display $\mathbf{e}_1$ and $\mathbf{v}_{ab\_oc}$ for about 2 cycles on channels 1 and 2 of your oscilloscope. Capture the image on the scope, and embed it in a Word document and label it properly, recording the value of $\mathbf{v}_{ab\_oc} = \mathbf{E}_{TH.}$ (remember everything has a phase angle now).
2) Replace the open circuit with a very small value resistor, R_{sample} to model a short circuit. It should be much less than 5% of the magnitude of your calculated value of $\mathbf{Z}_{TH}$ but large enough so that you can reliably measure a voltage with the oscilloscope. Display $\mathbf{e}_1$ and $\mathbf{v}_{Rsample}$ for about 2 cycles on channels 1 and 2 of your oscilloscope. Capture the image on the scope, and embed it in your Word document. Use Ohm's Law to calculate the value of the (almost) short circuit current $\mathbf{I}_{SC}$, and record it.
3) Use the measured values of $\mathbf{E}_{TH}$ and $\mathbf{I}_{SC}$ to calculate $\mathbf{Z}_{TH}$, and record this in your Word document.
4) <u>At this point you have enough information to sketch the experimentally determined Thevenin Equivalent Circuit</u>. Sketch the Thevenin Equivalent Circuit in your Word document and label it with the calculated values of $\mathbf{E}_{TH}$ and $\mathbf{Z}_{TH}$ from steps 1, 2 and 3. <u>Have your instructor sign-off on your experimentally determined Thevein Equivalent Circuit.</u>
5) Use the R-C substitution box as the load, $\mathbf{Z}_L$ for the circuit of Figure 1. Dial up the complex conjugate of $\mathbf{Z}_{TH}$ and make this value your load $\mathbf{Z}_{L1}$.
6) Measure the current $\mathbf{I}_{L1}$ through $\mathbf{Z}_{L1}$ and record it in your data table. Calculate and record the real power dissipated in the load, $\mathbf{P}_{L1}$ and record this in your data table.
7) Set $\mathbf{Z}_L = \mathbf{Z}_{L2} = 1000\ \Omega$. Determine the current $\mathbf{I}_{L2}$ through $\mathbf{Z}_{L2}$ and record it and the real power dissipated in the load, $\mathbf{P}_{L2}$ in your data table.
8) Set $\mathbf{Z}_L = \mathbf{Z}_{L3} = 15\ k\Omega$. Determine the current $\mathbf{I}_{L3}$ through $\mathbf{Z}_{L3}$ and record it and the real power dissipated in the load, $\mathbf{P}_{L3}$ in your data table.
9) <u>Have your instructor sign-off on your completed data table.</u>

Question

1. When was the maximum power transferred to the load (when $\mathbf{Z}_{L1}$, $\mathbf{Z}_{L2}$, or $\mathbf{Z}_{L3}$ was used)? In one short paragraph, explain why that is, using vectors or calculations to illustrate your discussion. This information will be considered in the post lab quiz.

Post Lab Requirements

After lab, **<u>during a time specified by your instructor</u>**, take the Post Lab Quiz on myCourses. You may use your prelab work, lab data and answers to the lab question as reference material.

Turn in your completed documentation at the beginning of next week's lab before you take that week's prelab quiz. Your submission package will be graded and returned with comments. Submit **<u>only the following pages (in order)</u>** <u>at the start of lab NEXT week:</u>

1. The following cover page, completely filled-in by all your team members with sign-offs, <u>one per team.</u>

2. Lab results in order <u>(one set per team, 3-6 pages):</u>

- **a**. Properly labeled oscilloscope plots from steps 1 and 2 with measurements, data and $\mathbf{E_{TH}}$ and $\mathbf{Z_{TH}}$ calculations (step 3)
- **b**. The experimentally determined Thevenin equivalent circuit <u>with component values</u>, properly annotated (step 4)
- **c**. Properly labeled oscilloscope plots from steps 5 and 6 with measurements, data and $\mathbf{I_{L1}}$, $\mathbf{P_{L1}}$ calculations.
- **d.** Your team's data table with all of your calculated and measured values, including percent error calculations where appropriate.
- **e**. Question 1, restated and accurately/completely answered

Lab Note: Phase angles in the Lab

In the AC world, everything has a phase angle. You have to remember that a phase angle is the angle between 2 phasors. Usually one of the phasors has an angle of 0° (zero). this is the reference angle, and all the other phase angles are measured relative to that. In the lab, there is no good way to give the supply voltage an initial phase angle. It's usually used as the reference or 0° phasor. In today's lab, however, you calculated $\mathbf{e}_{TH}$ and it has an angle θ associated with it. How can you use $\mathbf{e}_{TH}$ in the lab then? The answer is pretty simple. If you make $\mathbf{e}_{TH}$ the reference phasor, and all other measurements are taken relative to it, its phase angle can be thought of as 0°. All the other currents and voltages in the circuit will have their phase angles shifted the same amount in the same direction. Your calculation and measurement of $\mathbf{e}_{TH}\angle\theta$ for the original circuit is shifted from θ to 0° for use in the lab. Remember, Sine waves are circular by nature, so you cannot tell the difference between θ = 0° and θ = 360°. in the same way if all the angles are shifted the exact same amount, all the calculations for power, Ohm's law, KVL, KCL will work out the same way. Think of it this way, If you take a picture with the camera at an angle, it looks the same through your eyes whether you tilt your, or you tilt the picture. Shifting the reference angle which shifts all the voltage and current angles related to it the same amount is the same idea. Here's how it works in the lab:

Let $\mathbf{e}_{TH} = 20V\angle 30°$, and $\mathbf{R}_{TH} = 10\Omega\angle 20°$ Max power is realized when $R_L = 10\Omega\angle -20°$. Now if you calculate the current, the total impedance seen by $\mathbf{e}_{TH}$ is $1A\angle 30°$ ($20V\angle 30°/20\Omega\angle 0°$). so the applied voltage and resulting current is in phase and at a maximum. If you repeat this calculation with the source $\mathbf{e}_{TH} = 20V\angle 0°$ as reference, the current becomes $1A\angle 0°$ (Note the current shifts the same amount) and the power is still the same. Use this idea in the lab for measuring the load current, and when you calculate the power dissipated in the loads the results will be correct. (Remember, Power doesn't have an angle. it's not a phasor.)

What about impedance? Since Ohm's law tells us that $\mathbf{Z} = \mathbf{V}/\mathbf{I}$, when you shift the phase angles of **V** and **I** the same amount, the angle of Z will remain unchanged. Here's an example: $10V\angle 20°/10mA\angle -30° = 1k\Omega\angle 50°$. Now let's shift the phase angle on the voltage to 0°, and the phase angle of the current the same amount (-20°) which is exactly what would happen in the lab. Now: $10V\angle 0°/10mA\angle -50° = 1k\Omega\angle 50°$. Notice you'll get the same result when you calculate the impedance. Hopefully this gives you an insight into phasors in an AC Circuit. Make sure you ask your instructor to help you if any of the concepts are unclear.

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Team Name and Lab Section:..

Team Members Present (printed)

First Name, Last Name	Role This Lab	RIT Program

TEAM LABORATORY RESULTS GRADE

(all work done neatly, legible and properly organized, all signoffs in place, oscilloscope plots and annotations included, data table and Question 1 completed, no missing or extraneous information)

Instructor signature, Thevenin Equiv. (step 4) ________	/10
Plots, annotations and calculations (steps 1,2)	/10
Equivalent circuit with component values (steps 3,4)	/10

Instructor signature, Pmax data table (step 9) _______	/10
Plots, annotations and calculations (steps 5,6)	/5
Pmax data table (data, accuracy, units, proper format, % Error)	/10
Question 1 (restated, detailed answer, accurate, well thought out and articulated, WORD format)	/5

Final Team Grade .... **/60**

Instructor comments: