International University

School of Electrical Engineering

Principles of EE I Laboratory

EE052IU

Lab 7

Mesh and Nodal Analysis of AC Circuits

Submitted by

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GRADING GUIDELINE FOR LAB REPORT

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	- Grammar	Yes No		
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Nomenclature

V_T= Thévenin voltage

Vc= Voltage of capacitor

VL= Voltage of inductor

I_C : Current through capacitor

I_L : Current through inductor

Z_C : Impedance of capacitor

Z_L : Impedance of inductor

V_R : Voltage of resistor

I_R : Current through resistor.

R : Resistance

Etc.

Theoretical Background

1. Mesh-Current Analysis (KVL):

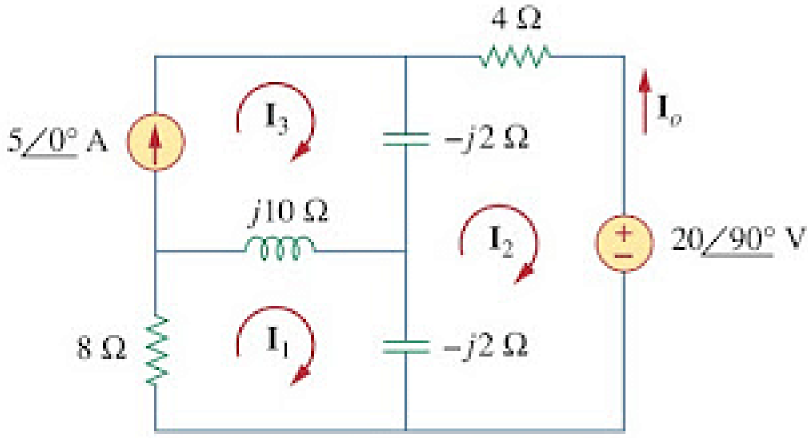

Figure 1. AC mesh-current method example for AC

AC mesh analysis uses Kirchhoff's Voltage Law (KVL), which states that the algebraic sum of all voltages around any closed loop in a circuit must equal zero. In AC circuits, this means summing complex voltages around a loop.

For mesh analysis, the following steps are taken:

1. Convert all AC sources and impedances to their phasor equivalents.

2. Identify independent loops in the circuit, and assign a mesh current to each loop.

3. Apply KVL around each loop, expressing the voltages in terms of the mesh currents and complex impedances.

4. Solve the resulting simultaneous complex equations to find the mesh currents.

2. Node-Voltage (KCL):

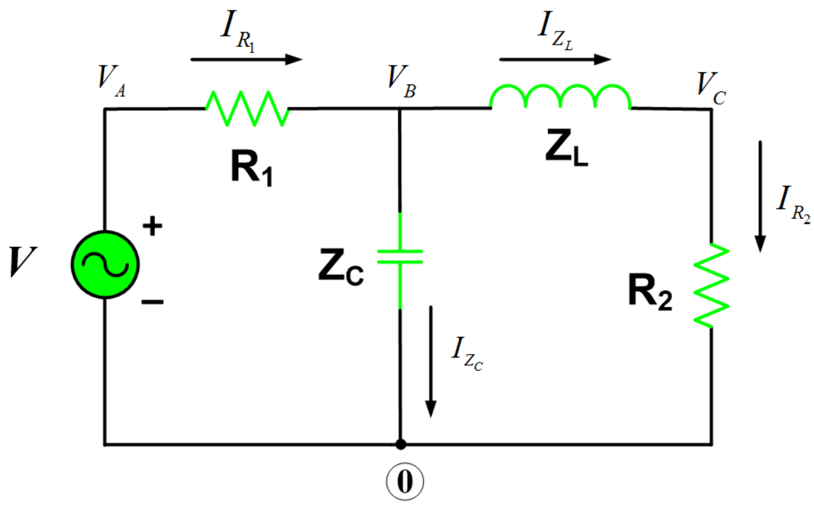

Figure 2. Node-voltage method example for AC

AC nodal analysis involves applying Kirchhoff's Current Law (KCL) at the nodes in a circuit. The law states that the algebraic sum of currents at any node is zero. In an AC circuit, currents are complex because they consist of both magnitude and phase. This means the analysis must be done using complex numbers or phasors to represent the sinusoidal voltages and currents.

For nodal analysis, the following steps are generally taken:

1. Convert all AC sources and impedances to their phasor (frequency domain) equivalents.

2. Choose a reference node (ground), and assign node voltages to the remaining nodes.

3. Apply KCL at each node except the reference, expressing the currents in terms of the node voltages and complex impedances.

4. Solve the resulting simultaneous complex equations to find the node voltages.

Once node voltages are known, any current or voltage in the circuit can be found using Ohm's law.

Both analyses require the use of complex arithmetic and are often facilitated by matrix methods, such as the use of determinants or linear algebra software. The results will give you the phasor form of voltages or currents, from which you can then determine the time-domain expressions if required.

In both nodal and mesh analysis, the use of complex impedance is crucial. Impedance in AC circuits combines resistance (R), inductive reactance ($XL = \omega L$), and capacitive reactance ($XC = 1/(\omega C)$), where ω is the angular frequency of the AC source. The complex impedance can be represented as $Z = R + j(XL - XC)$, where j is the imaginary unit.

These methods provide a systematic approach to analyzing AC circuits, especially when dealing with multiple sources and components interacting at various frequencies

Set-up steps:

Creating dual-channel supply:

The initial phase of the experiment requires the establishment of two AC voltage sources as specified for the circuit in Figure 1. The following steps are to be undertaken:

1. Inspect the cables to confirm their functionality.
2. Activate the function generator and connect two cables, ensuring both channels are operational.
3. Configure the generator settings to match the required frequency, peak voltage, and phase angle as directed in the lab manual.

A notable challenge encountered is the function generator's inability to process negative phase angles. To circumvent this, we utilize the cyclic properties of phasors. For instance, a -46° phase shift is equivalent to a positive shift of 314°, which is within the acceptable range of the function generator.

Figure 3. Dual-channel AC setting

Figure 4. The 0.01uF ceramic capacitor – 103

Function of a capacitor:

- Tuing circuit
- Power conversion and regulation
- Storing Energy

Experimental Procedure and Results:

1. Mesh-current Analysis:

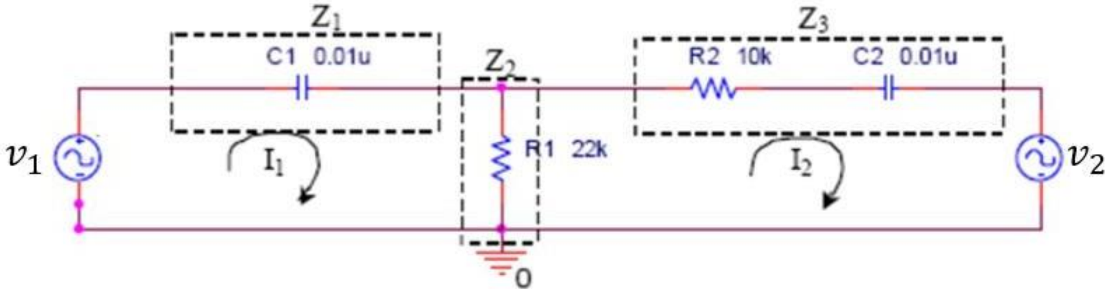

Figure 5. AC network used in the mesh-current analysis

Calculation/Simulation:

For calculation:

- Given that:

$v_1(t) = 5\sin(2\pi 1000t + 0°)$ [V]

$v_2(t) = 3\sin(2\pi 1000t - 46°)$ [V]

By using Mesh-current method, we have:

$$Loop\ 1: I_1(Z_c + 22000) + I_2(-22000) = 5 < 0$$

$$A = (Z_c + 22000), B = (-22000), E = 5 < 0$$

$$Loop\ 2: I_1(-22000) + I_2(32000 + Z_c) = -3 < -46^0$$

$$C = (-22000), D = (32000 + Z_c), F = -3 < -46^0$$

$$Z_C = \frac{1}{j\omega C} = -j15915.49431\ (Ohm)$$

$$By\ using\ Crammer's\ Rule: D = \begin{vmatrix} A & B \\ C & D \end{vmatrix} = AD - CB$$

$$D_x = \begin{vmatrix} B & E \\ D & F \end{vmatrix} = BF - DE$$

$$D_y = \begin{vmatrix} A & E \\ C & F \end{vmatrix} = AF - CE$$

$$I_1 = x = \frac{D_x}{D} = 1.37857 \times 10^{-4} < 76.53^{\circ}$$

$$I_2 = y = \frac{D_y}{D} = 1.48070 \times 10^{-4} < 131.53^{\circ}$$

$$V_{z1} = I_1 \times Z_{C1} = 2.194 < -13.47^{\circ}$$

$$V_{z2} = 22000(I_1 - I_2) = 2.91 < 10.105^{\circ}$$

$$V_{z3} = I_2(10000 - j15915.49431) = 2.783 < 73.67^{\circ}$$

Complex Form : $x_1 = 0.000032106 + j0.000134066$ Polar Form $x_1 = 0.000137857\ \angle 76.532672972^{\circ}$

Complex Form : $x_2 = -0.000098180 + j0.000110840$ Polar Form $x_2 = 0.000148070\ \angle 131.533879756^{\circ}$

Figure 6 . Simulation results for I1 and I2

For measurement:

a. Measurement of Voltage Signals:

Begin by measuring the voltage signals at the V2 source and at node Z2, which serves as the reference signal. Record these voltage magnitudes to determine the voltage magnitude of VZ3.

b. Phase Difference Calculation (Delta Phase) of V2 and Z2:

Utilize the oscilloscope's math function to calculate the phase difference between the V2 source and the node Z2. Denote this value as Delta Phase (1).

c. Measurement of Additional Voltage Signals:

Measure the voltage signals of the V2 source and the V1 source, with the V1 source acting as the reference signal.

d. Phase Difference Calculation of V1 and V2:

Again, apply the oscilloscope's math function to find the phase difference between the V1 source and the V2 source. Label this as Delta Phase (2).

e. Final Phase Calculation of VZ3:

Determine the phase of VZ3 by adding the phase differences obtained in steps 2 and 4 (Delta Phase (1) + Delta Phase (2)).

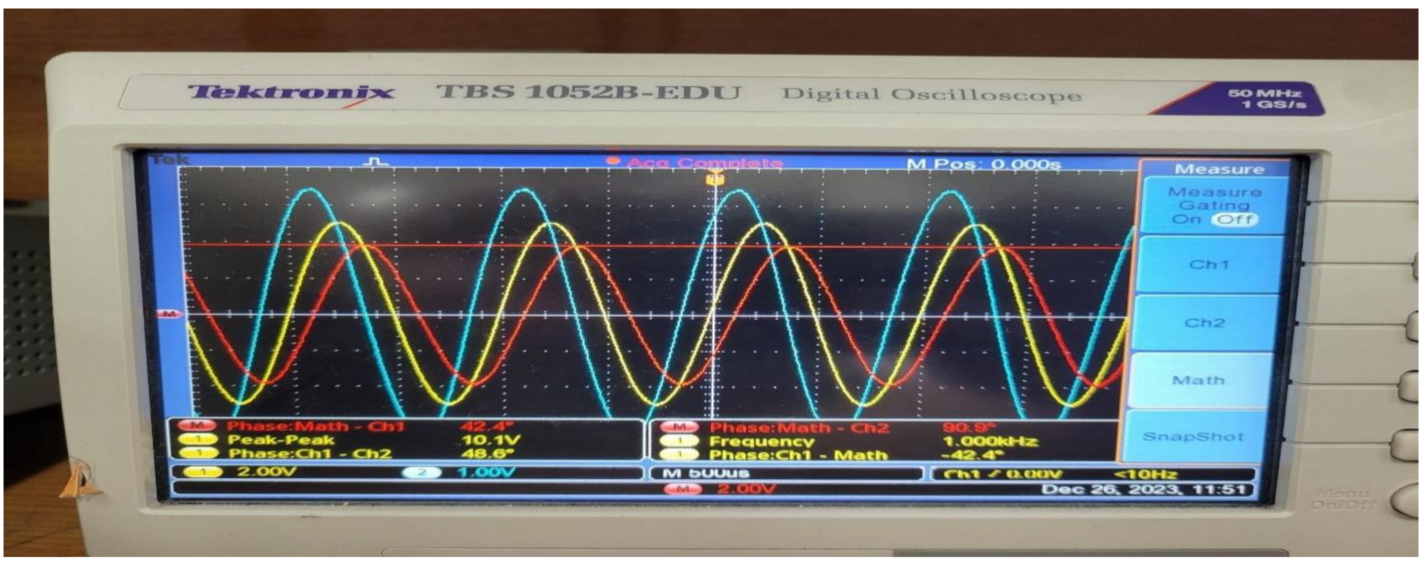

Figure 7. How the previous steps for measurement

	$V_{peak}\angle\phi°$

	Calculated/simulated	Measured
V_{Z1}	$2.19 < -13.47^{\circ}$	2.52 < 84.2°
V_{Z2}	$2.91 < 10.105^{\circ}$	2.88 < 66.8°
V_{Z3}	$2.783 < 73.67^{\circ}$	2.96 < -107°
I_1	$0.137857\ mA < 76.53^{\circ}$	0.154 mA < -110°
I_2	$0.148070\ mA < 131.53^{\circ}$	0.167 mA < 11°

Table 1. Measurement results for mesh-current analysis

	Errors (%)
V_{Z1}	15.07%
V_{Z2}	1.03%
V_{Z3}	6.36%
I_1	12.41%
I_2	12.83%

Table 2. Measurement errors for mesh-current analysis

Comment base on results:

In our AC mesh-current method lab, we observed some discrepancies between our calculated/simulated and measured results. The voltage magnitudes VZ1, VZ2, and VZ3 displayed errors of 15.07%, 1.03%, and 6.36% respectively, with VZ2 demonstrating a high degree of accuracy, suggesting reliable modeling for that particular component of the circuit. However, significant phase angle discrepancies for VZ1, VZ3, I1, and I2 were noted, with errors possibly stemming from instrumentation calibration, measurement inaccuracies, or the inherent limitations of the simulation model. These findings highlight the importance of precise measurement and calibration techniques, as well as the need for careful consideration of component tolerances and potential setup errors in circuit analysis and simulation. Future experiments will benefit from addressing these factors to enhance the accuracy of our results.

2. Node-voltage Analysis

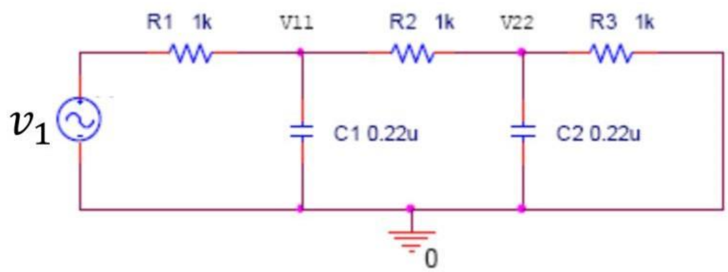

Figure 8. AC circuit used in the Node -voltage Analysis

For Calculation

Given that:

$v_1(t) = 5\sin(2\pi 1000t + 0°)$ [V]

Node-voltage method:

Node 1:

$$\frac{V_{11} - 5 < 0}{1000} + \frac{V_{11} - V_{22}}{Z_C} + \frac{V_{11} - V_{22}}{1000} = 0$$

$$V_{11}\left(\frac{100}{72343}j\right) + V_{22}\left(\frac{-1}{1000} - \frac{100}{72343}j\right) = \frac{-1}{200}$$

$$A = \frac{100}{72343}j, \qquad B = \frac{-1}{1000} - \frac{-100}{72343}j, \qquad E = \frac{-1}{200}$$

Node 2:

$$\frac{V_{22} - V_{11}}{1000} + \frac{V_{22}}{Z_C} + \frac{V_{22}}{1000} = 0$$

$$V_{11}\left(\frac{-1}{1000}\right) + V_{22}\left(\frac{1}{500} + \frac{100}{72343}j\right) = 0$$

$$C = \frac{-1}{1000}, \qquad D = \frac{1}{500} + \frac{100}{72343}j, \qquad F = 0$$

$$By\ using\ Crammer's\ Rule: D = \begin{vmatrix} A & B \\ C & D \end{vmatrix} = AD - CB$$

$$D_x = \begin{vmatrix} B & E \\ D & F \end{vmatrix} = BF - DE$$

$$D_y = \begin{vmatrix} A & E \\ C & F \end{vmatrix} = AF - CE$$

$$V_{11} = x = \frac{D_x}{D} = 3.772 < -119.95^{\circ}$$

$$V_{22} = y = \frac{D_y}{D} = 1.55 < -154.60^{\circ}$$

$$V_{R1} = I_{R1} \times 1000 = \frac{5 < 0 - V_{11}}{1000} \times 1000 = 4.516 < -46.36^{\circ}$$

$$V_{R2} = I_{R2} \times 1000 = \frac{V_{11} - V_{22}}{1000} \times 1000 = 2.649 < -100.51^{\circ}$$

$$V_{R3} = I_{R3} \times 1000 = \frac{V_{22}}{1000} \times 1000 = 1.55 < -154.60^{\circ}$$

Complex Form : $x_1 = -1.883197256 - j3.268788030$ Polar Form $x_1 = 3.772453723 \angle -119.946882459^{\circ}$

Complex Form : $x_2 = -1.401655175 - j0.665637419$ Polar Form $x_2 = 1.551679865 \angle -154.597244523^{\circ}$

Figure 9. Simulation results for V11 and V22

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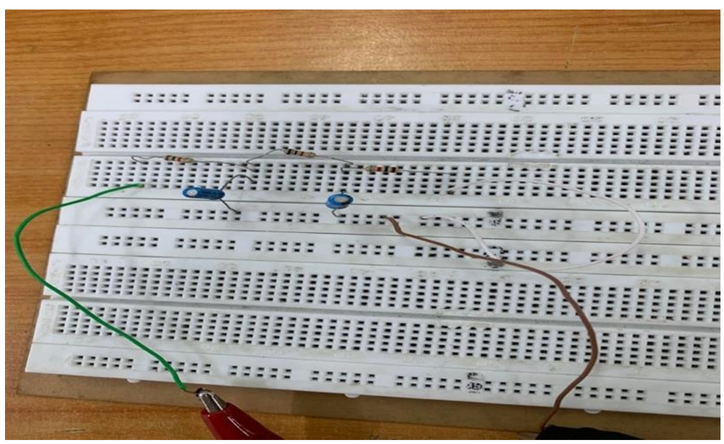

Figure 10 . Constructed circuit for Node-voltage Analysis

For measurement:

To conduct the AC node-voltage method experiment, we first set up the circuit and connected it to a Function Generator. We carefully adjusted the peak-to-peak voltage, frequency, and phase shift to match the required specifications (Step 1).

Next, we connected the circuit to an Oscilloscope to observe and measure the phase shift of our voltage waveform compared to a reference waveform (Step 2).

Using the Oscilloscope's Cursor function, we measured the time difference to calculate the phase shift. The Measure function helped us confirm these values (Step 3).

Finally, we measured the voltage across specific components in the circuit, relying on the Oscilloscope for precise readings (Step 4).

Each step was carried out methodically to ensure accurate and useful data for our analysis.

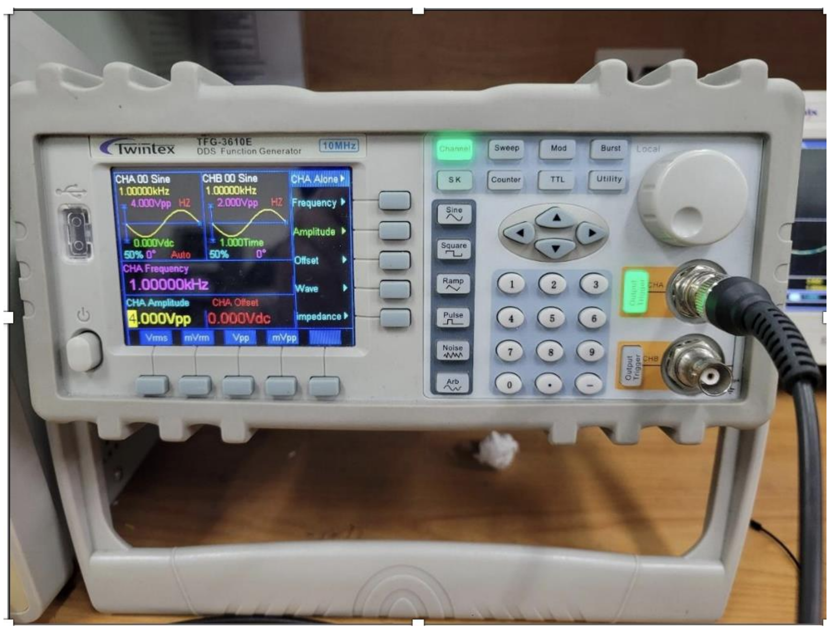

Figure 10. Setting-up steps for experiment

	$V_{peak}\angle\phi^{\circ}$	
	Calculated/ Simulated	Measured
V_{R1}	$4.516 < -46.36^{\circ}$	$4.216 < 50.56^{\circ}$
V_{C1}	$3.772 < 60.05^{\circ}$	$5.215 < -23.21^{\circ}$
V_{R2}	$2.649 < -100.51^{\circ}$	$3.042 < 130.59^{\circ}$
V_{C2}	$1.55 < 25.40^{\circ}$	$2.21 < 52.46^{\circ}$
V_{R3}	$1.55 < -154.60^{\circ}$	$2.31 < -121.53^{\circ}$
V_{11}	$3.772 < -119.95^{\circ}$	$4.024 < 166.25^{\circ}$
V_{22}	$1.55 < -154.60^{\circ}$	$1.23 < -123.40^{\circ}$

Table 3. Measurement results for node-voltage method

	Error (%)
V_{R1}	6.64%
V_{C1}	38.26%
V_{R2}	14.84%
V_{C2}	42.58%
V_{R3}	49.03%
V_{11}	6.68%
V_{22}	20.64%

Table 4. Measurement error in table 3

Comment on the results:

The results from the AC node-voltage method experiment reveal a disparity between the calculated and measured values, indicating the need for closer examination of the experimental setup and verification processes. While the voltage across VR1 showed a minimal error, suggesting a relatively accurate representation of this portion of the circuit, the significant errors observed in VC1, VC2, and VR3 highlight potential inaccuracies in component values or measurement techniques. Moreover, the phase angle deviations point toward possible issues with instrument calibration or the phase characteristics of the circuit elements. To enhance the accuracy of future experiments, a thorough review of the equipment calibration, component tolerances, and measurement procedures is recommended.

Discussion of Results

1. AC mesh-current analysis:

Our AC mesh-current analysis revealed disparities between calculated and measured values. The voltage across VZ1 showed a significant deviation, which might be attributed to experimental errors or component non-idealities. VZ2's close agreement between calculated and measured values suggests a valid model for this part of the circuit. However, the phase angles for VZ1, VZ3, I1, and I2 differed markedly from expected values, indicating potential errors in measurement technique or instrument calibration. These results emphasize the importance of accurate setup and verification of simulation assumptions. Future experiments should focus on improving measurement accuracy and refining simulation models to better match observed behavior.

2. AC node-voltage analysis:

The experiment's objective to validate the AC node-voltage method revealed a disparity between expected and measured voltages, indicating the method's partial success and highlighting the need for refinement. The low error in VR1's voltage confirms the method's reliability for some components. Yet, the high errors in VC1, VC2, and VR3's voltages suggest inaccuracies in component values, measurement techniques, or limitations within the simulation model, particularly for reactive components like capacitors.

The significant phase angle deviations across components imply potential issues with the measurement instruments or techniques, especially concerning calibration and phase response accuracy.

For enhanced correlation between theoretical and practical outcomes, we must:

1. Verify component values and account for their tolerances.
2. Ensure measurement instruments are calibrated correctly.
3. Refine the simulation model to better represent the circuit's behavior, especially for reactive elements.
4. Review and possibly revise the phase measurement methodology.

Preferences

1. https://www.bitdrivencircuits.com/Circuit_Analysis/Phasors_AC/meshHome.html
2. https://edurev.in/t/243571/Mesh-Supermesh-for-AC-Circuits
3. https://electricalacademia.com/circuits-with-matlab/node-voltages-calculation-in-an-ac-circuit-using-matlab