Project 4: AC Analysis via Netlist

Introduction

To analyze circuits with sinusoidal sources, the circuits will often be converted to the *frequency-domain* in which the circuit's elements are represented by corresponding complex numbers (phasors for voltages and currents; impedances for resistors, inductors and capacitors). An example of the two representations of a circuit with a sinusoidal source are shown in Figures 1 and 2. Figure 1 shows the circuit in the *time-domain* with voltages and currents as sinusoids, and Figure 2 shows the circuit in the *frequency-domain* with voltages and currents as complex numbers. Analysis of these types of circuits in sinsusoidal steady-state is referred to as AC (Alternating Current) Analysis.

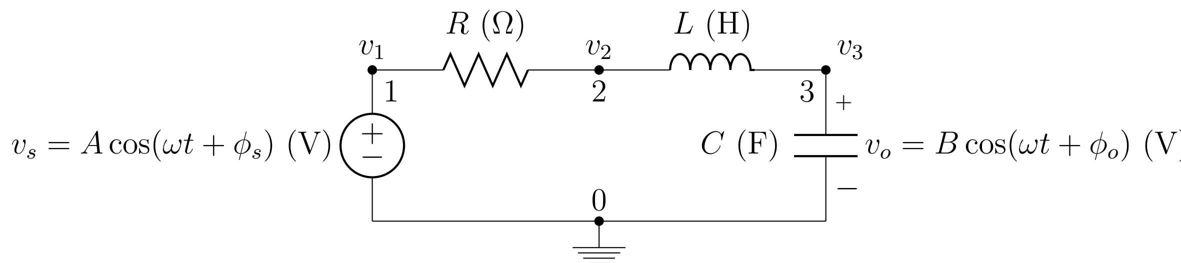

Figure 1: Series RLC circuit with sinusoidal source represented in time-domain

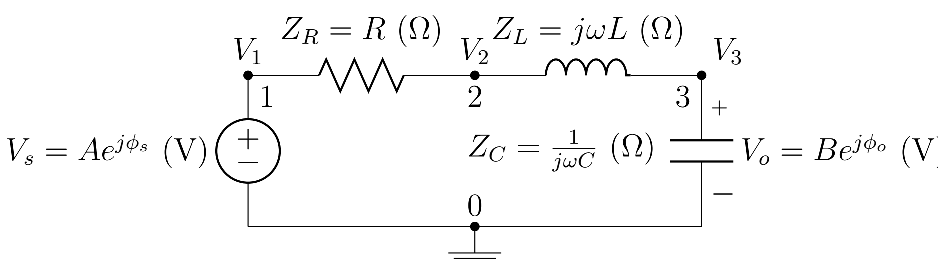

Figure 2: Series RLC circuit with phasor source represented in frequency-domain

Circuits have the same layout (topology) whether they be shown in the *time-domain* or *frequency-domain*, and it is common to describe them via a list of connections (referred to as a netlist in simulators for circuits). An example of the netlist adopted for this project is shown in Figure 3. Note the netlist will be a cell array and has a specific structure in terms of the two nodes to which elements are connected as well as their names (as a character) and values. This netlist describes the circuits shown in Figures 1 and 2 where numbers $(0, 1, 2, 3$ for this specific circuit) are used to identify connection points (nodes) between two or more elements within the circuit.

```
NL = { ...
     'S', 1, 0,   12, 60,  0 % Source   , FromNode(+), ToNode(-), Amp (V)     , Freq (Hz), Angle (rad)
     'R', 1, 2,  1e3, [], [] % Resistor , FromNode   , ToNode   , Value (Ohm) ,          ,
     'L', 2, 3, 1e-3, [], [] % Inductor , FromNode   , ToNode   , Value (H)   ,          ,
     'C', 3, 0, 1e-6, [], [] % Capacitor, FromNode   , ToNode   , Value (F)   ,          ,
     'O', 3, 0,   [], [], [] % Output   , FromNode(+), ToNode(-),             ,          ,
     };
```

Figure 3: Netlist for series RLC circuit as cell array

One node is chosen as the reference node (denoted 0) to which the voltages $(v_1, v_2, \ldots, v_{N-1})$ at all other nodes will be referenced/defined. Through application of Kirchhoff's Current Law (KCL) at each nonzero/non-reference node and making note of which nodes are connected directly to a known voltage source, a linearly independent set of equations can be written in terms of the node-voltages, and ultimately placed in matrix/vector form as shown below.

$$\underbrace{\begin{bmatrix} 1 & 0 & 0 \\ -\frac{1}{Z_R} & \frac{1}{Z_R}+\frac{1}{Z_L} & -\frac{1}{Z_L} \\ 0 & -\frac{1}{Z_L} & \frac{1}{Z_L}+\frac{1}{Z_C} \end{bmatrix}}_{Y} \underbrace{\begin{bmatrix} V_1 \\ V_2 \\ V_3 \end{bmatrix}}_{\vec{V}} = \underbrace{\begin{bmatrix} V_s \\ 0 \\ 0 \end{bmatrix}}_{\vec{K}} \tag{1}$$

N is the total number of (unique) nodes in the circuit, Y is a $N-1 \times N-1$ matrix that is a modified version of what is typically referrred to as the admittance matrix, $\vec{V}$ is the vector of unknown node-voltages, and $\vec{K}$ is the vector of known node-voltages (sources). Equation (1) comes directly from the circuit shown in Figure 2 and described by the netlist in Figure 3, and has considerable structure that make it readily constructed via a computer program. Complex impedances $Z_R = R\ \Omega$, $Z_L = j\omega L\ \Omega$, and $Z_C = \frac{1}{j\omega C}\ \Omega$ are computed directly from values of resistance, inductance, and capacitance, respectively, given the source's angular frequency ω.

Problem Statement

The goal of this project is to write a Matlab program that computes the output voltage of a circuit (represented by a netlist) using AC analysis, linear algebra, and the relationship between the *time-domain* and *frequency-domain*. Specifically, the Matlab program should

1. load a specified netlist stored as a cell-array within a mat-file (see the examples *circuit1.mat*, *circuit2.mat*, ... linked on the web page);
2. use the netlist to construct the admittance matrix Y and vector of knowns $\vec{K}$;
3. solve the matrix-vector equation $Y\vec{V} = \vec{K}$ for the unknown node-voltages $\vec{V}$;
4. compute the desired complex output voltage V_o from the complex node-voltages $\vec{V}$;

5. compute and plot the sinusoidal source voltage v_s and output voltage v_o on the same figure;

6. be easily modified for other mat-files that contain netlists for other circuits; and

7. be neatly coded, i.e., has appropriate variable names, nice formatting and comments.

Assumptions about the Netlist's Format

The following can be assumed about the format of the netlists:

- reference node will always be numbered 0 such that $v_0 = V_0 = 0$ V;

- node-voltages v_i, V_i have polarity (+, -) assigned between corresponding (node i, reference node 0);

- one sinusoidal (cosine) voltage source will be present with polarity (+, -) indicated by its (FromNode, ToNode = 0), i.e., the voltage source's ToNode will always be 0;

- one output voltage with polarity (+, -) will be requested as indicated by its (FromNode, ToNode), i.e., $v_o = v_{FromNode} - v_{ToNode}$;

- resistors, inductors and capacitors can be placed arbitrarily between any two nodes (FromNode, ToNode); and

- nodes will be sequentially numbered as $0, 1, 2, \ldots, N-1$ where N is the total number of nodes in a circuit.

Items to Turn In

- Hand in a printed document that includes memo, Matlab program, and results (complex values for Y, $\vec{V}$, $\vec{K}$, V_o, and plots of the input and output sinusoids) for at least one of the sample netlists given as well as the circuit shown below (including your netlist).

- Email Matlab program to instructor such that program can be readily ran with alternate netlists as mat-files. Put "EE 251 Project 4" in the subject line of the email.

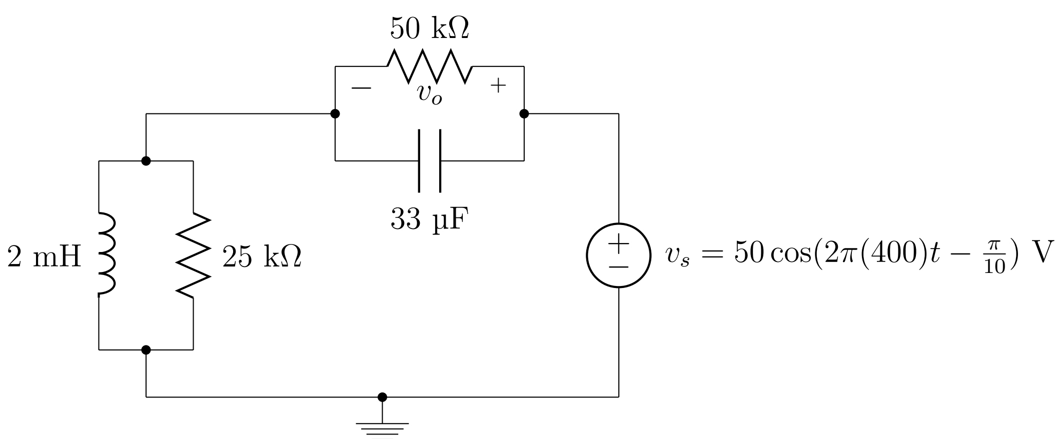

Figure 4: Circuit with sinusoidal source represented in time-domain