**Project**

A circuit simulation project to transition you from *lumped component*-based circuit theory

In Part 1 and Part 2, you built an LC network:

And, you did transient simulations of the following circuits with the generator signal being voltage steps with different rise times (0.1 ns and 1 ps):

Part 3: Now, create a new network that is a cascade of 10 instances of the above LC network. You may create a symbol for this new network for convenience. Using the same inductance and capacitance values to do the same simulations you have done for the above single LC network. (Same generators with same internal impedance. Simulate for both open circuit and 50-ohm loads, the two rise times for each case, as done for the single LC.)

Ongoing project. Stay tuned for next steps.
Project

A circuit simulation project to transition you from lumped component-based circuit theory

In Part 1 and Part 2, you built an LC network:

In Part 3, you built a cascade of 10 instances of this LC network.

And, you did transient simulations of the following circuits (with the 1-unit and 10-unit networks) with the generator signal being voltage steps with different rise times:

Part 4: Now, create a new network that is a cascade of 10 instances of the 10-unit network, so that this new network contains 100 units. You may create a symbol for this new network for convenience. Using the same inductance and capacitance values, do the same simulations you have done for the above 1- and 10-unit networks. (Same generators with same internal impedance. Simulate for both open circuit and 50-ohm loads, the two rise times for each case, as done for the single LC.)

Ongoing project. Stay tuned for next steps.
Project

A circuit simulation project to transition you from lumped component-based circuit theory

In Part 1 and Part 2, you built an LC network:

In Part 3, you built a cascade of 10 instances of this LC network. In Part 4, you built a cascade of ten such 10-unit networks, which is 100-unit.

And, you did transient simulations of the following circuits (with the 1-unit and 10-unit networks) with the generator signal being voltage steps with different rise times:

Part 5: Now, create a new network that is a cascade of 10 instances of the 100-unit network, so that this new network contains 1000 units. Using the same inductance and capacitance values, do the same simulations you have done for the above 1-, 10-, and 100-unit networks.

Ongoing project. Stay tuned for next steps.
Part 6: A lossless transmission line system is shown as above. The generator generates an ideal step function with a 1 V step height. The transmission line parameters are as follows: Unit length inductance $L' = 0.3 \text{ nH/mm}$, unit length capacitance $C' = 0.12 \text{ pF/mm}$. Calculate the characteristic impedance $Z_0$ of the line and the phase velocity $v_p$. Plot the waveforms of $V_1$ and $V_2$. How do you relate these waveforms to the simulations you have done?

Note: This part is not to be done by simulation. You do the analysis.

Now, the 50 Ω load is replaced with an open circuit. Plot the waveforms of $V_1$ and $V_2$. (You may construct a bounce diagram if needed.) How do you relate these waveforms to the simulations you have done?
Part 7: Consider the lossless transmission line system (shown above) of Part 6. Do AC analysis manually (actually mentally!) and sketch plots the following: $\left| \frac{\bar{V}_2}{\bar{V}_1} \right|$, phase of $\frac{\bar{V}_2}{\bar{V}_1}$, $\left| \frac{\bar{V}_1}{\bar{I}_1} \right|$, and phase of $\frac{\bar{V}_1}{\bar{I}_1}$, against frequency $f$ (or $\omega = 2\pi f$). Use linear scales. For the magnitude ratios, do not use dB (which put the ratios actually on the log scale). For the phases, make it clear whether you use degree or radian as the unit.

Let $\Delta \phi$ be the phase of $\frac{\bar{V}_2}{\bar{V}_1}$. Sketch a plot of $\frac{d}{df} \Delta \phi$ or $\frac{d}{d\omega} \Delta \phi$ against frequency $f$ (or $\omega = 2\pi f$).

Explain the physical meanings of the quantities plotted above.

Hint: A lossless transmission line is an ideal delay element (delay line), with the delay being the propagation time.
Part 8: Consider the circuit (shown above, with 1000 units) of which you did transient simulation in Part 5. Do AC simulation and plot the following: $|\frac{V_2}{V_1}|$, phase of $\frac{V_2}{V_1}$, $|\frac{V_1}{I_1}|$, and phase of $\frac{V_1}{I_1}$, against frequency $f$ (or $\omega = 2\pi f$, if you want to convert). Use linear scales. For the magnitude ratios, do not use dB (which put the ratios actually on the log scale). For the phases, make it clear whether you use degree or radian as the unit. Hint: Since you are plotting on linear scales, you should choose frequencies with equal intervals (i.e., on a linear scale). Simulate up to $f = 60$ GHz is sufficient.

Let $\Delta \varphi$ be the phase of $\frac{V_2}{V_1}$. Plot $\frac{d}{df} \Delta \varphi$ or $\frac{d}{d\omega} \Delta \varphi$ against frequency $f$ (or $\omega = 2\pi f$).

Hint: The simulation results will not be as “neat” as the plots in Part 6. You may want to generate more than one plot for each quantity to show details (i.e. to “zoom in”).

Explain the physical meaning of the quantities plotted above.

Hint: Such a cascade is often called an “artificial transmission line” or simply an “artificial line”. To better understand it, you may search for information using these key words. T. H. Lee’s *The Design of CMOS Radio-Frequency Integrated Circuits* has a good discussion. UT Library has it; you may also borrow from me.
Part 9: Now, quantitatively compare your transient analysis of the transmission line system (above, left) in Part 6 with the simulation of the circuit (above, right) in Part 5. What similarities do you observe? What differences do you observe?

To understand the above similarities and differences, compare your AC analysis of the transmission line system in Part 7 with the circuit AC simulation in Part 8. What similarities do you observe? What differences do you observe?

How do you relate the similarities in transient results to the similarities in AC results? How do you relate the differences in transient results to the differences in AC results? How do you explain the observed differences? Hint: Extra simulations may be helpful. For example, you may do the transient simulations with a much longer rise time, say, 1 ns. Analysis of the spectra of the step functions (with different rise times) used may also be helpful. It may also be helpful to look into the internal nodes of the circuit in both transient and AC simulations, e.g., get similar results as done in Parts 5 & 7 but for a single stage in the cascade; these results may be compared to the AC simulation of a single stage, of which you did transient simulation in Part 2 (see lower right figure of the first slide).

Conclude with what you have learned in this project.

The End