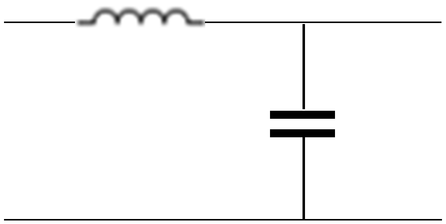
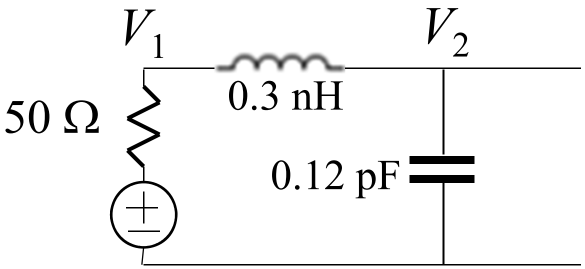
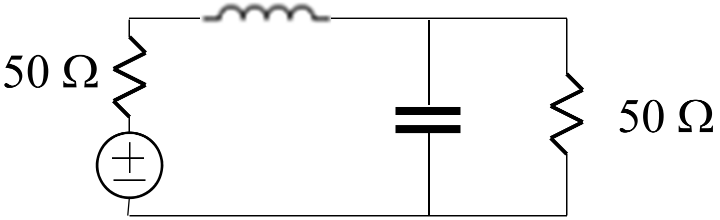
Project

Circuit simulations to transition you from lumped element-based circuit theory



Part 1





Generator: 1 V step, rise time = 0.1 ns. Internal impedance 50 Ω.

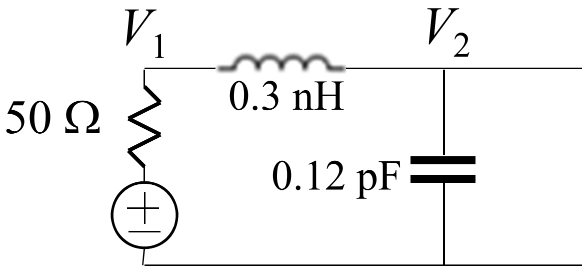
Plot the two voltages V_1 and V_2 for the above two cases.

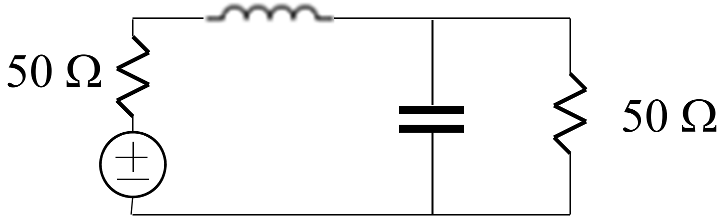
Hint: You may make mistakes. Do a sanity check by a “back of an envelope” analysis.
At the very least, find out the steady state.
Does the simulation give you more or less what you expect?

Ongoing project. Stay tuned for next steps.

Project

Part 2





Part 1

Generator: 1 V step, rise time = 0.1 ns. Internal impedance 50 Ω.

Plot the two voltages V_1 and V_2 for the above two cases.

What have you got?

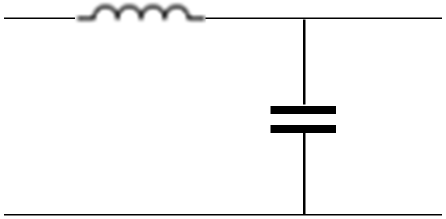
Now, do the same simulations for rise time = 1 ps.
Notice that you might need to set MaxTimeStep & StopTime. Try different values for these and see what difference you make by changing them.
Also, adjust the scales of the plots to show details.
Do not forget to do a sanity check.
Compare the results to those of Part 1. Similarities and differences?
Do the results make sense to you?

Ongoing project. Stay tuned for next steps.

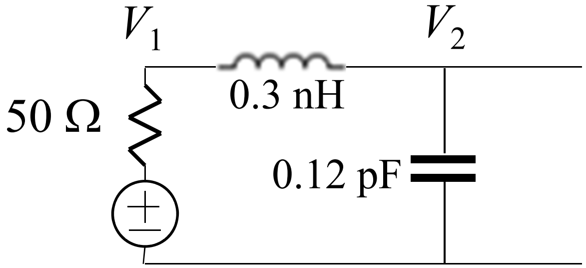
Project

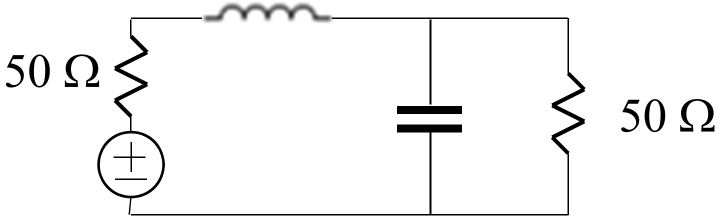
A circuit simulation project to transition you from lumped component-based circuit theory

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



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):





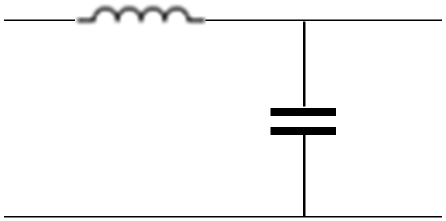
Part 3: Now, create a new network that is a cascade of 10 instances of the above LC network. You may create a symbol for this new network for convenience. Using the same inductance and capacitance values to do the same simulations you have done for the above single LC network. (Same generators with same 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

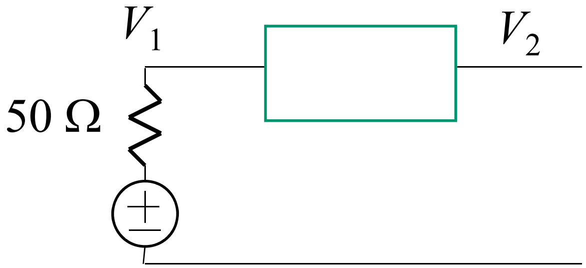
A circuit simulation project to transition you from lumped component-based circuit theory

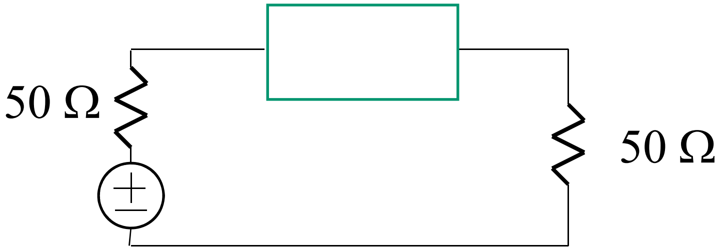
In Part 1 and Part 2, you built an LC network:



In Part3, 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:

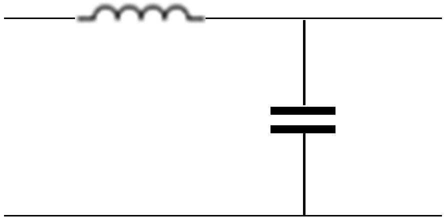




Part 4: Now, create a new network that is a cascade of 10 instances of the 10-unit network, so that this new network contains 100 units. You may create a symbol for this new network for convenience. Using the same inductance and capacitance values, do the same simulations you have done for the above 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.)

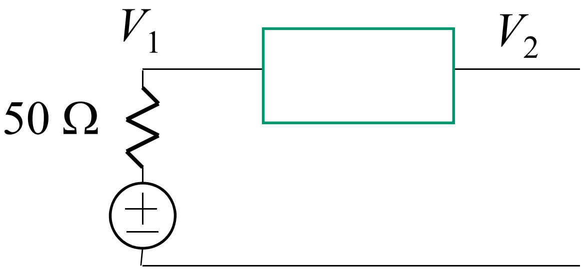
Ongoing project. Stay tuned for next steps.

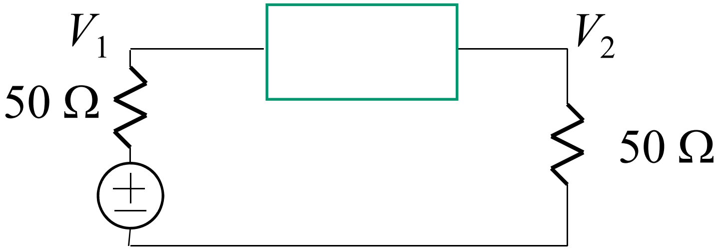
Project



In Part3, 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:



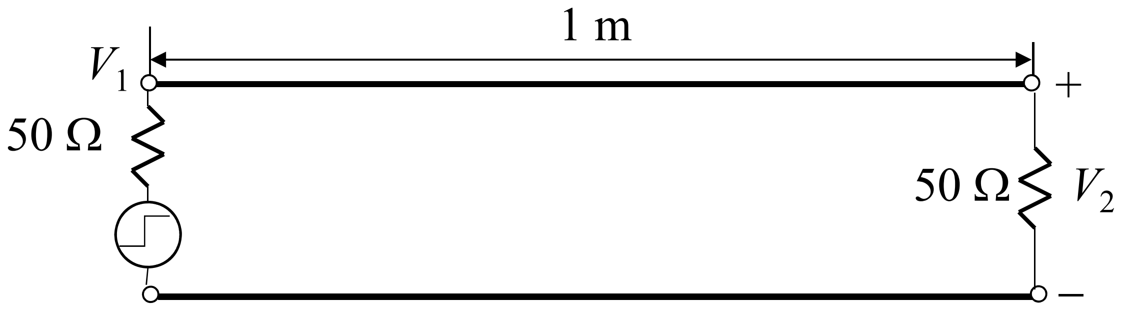


Part 5: Now, create a new network that is a cascade of 10 instances of the 100-unit network, so that this new network contains 1000 units. Using the same inductance and capacitance values, do the same simulations you have done for the above 1-, 10-, and 100-unit networks.

Note: You want to see the entire transient process (until it essentially settles). You may also want to see the details of the transients, e.g. the details of the rises and falls. To see the entire thing and the details, you may want to plot on different scales. If you are curious about the transients at the internal nodes of the cascades, plot those and see. Need help with the tool to do that, ask the TA.

Ongoing project. Stay tuned for next steps.

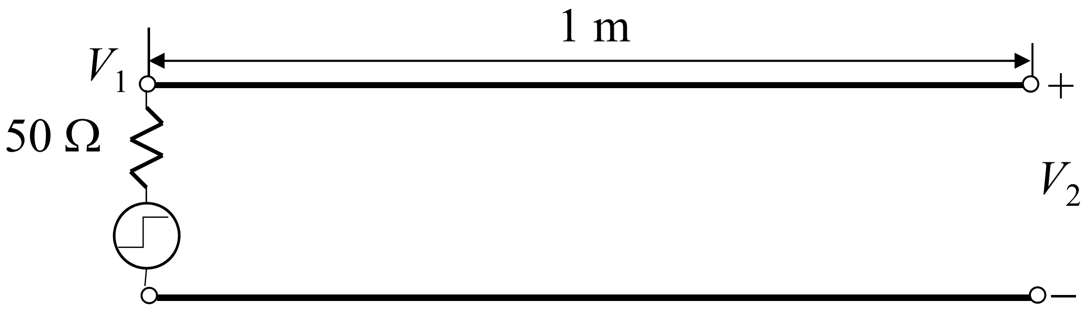
Note: This part is not to be done by simulation. You do the analysis.



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 nH/mm, unit length capacitance C' = 0.12 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?



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?

In Part 6, you compared the step responses of two transmission line systems (terminated in a 50 Ω load and in an open circuit, respectively) with the simulated responses of the LC networks in earlier parts. You must be wondering about the similarities and differences. Now, we have more simulations for you to do, and you can observe more:

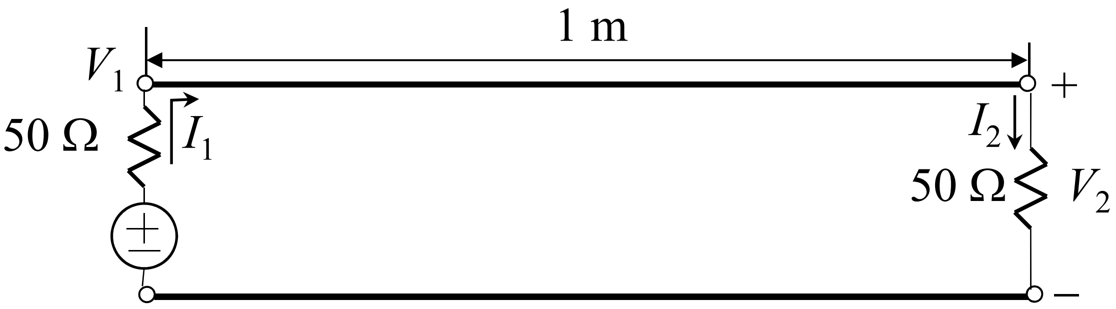
Part 7: Repeat the simulations you did in Parts 3 through 5, but with $L = 0.03$ nH and $C = 0.012$ pF. Then, build a cascade of 10 × 1,000 = 10,000 units and do the same simulations.

Since the new L and C values are a factor of 10 smaller, the 10-unit cascade has the same total inductance and capacitance as the old single-unit network, the 100-unit cascade has the same total inductance and capacitance as the old 10-unit cascade, and so on. Compare the new simulation results of the 10-unit with those of the old single unit, the new 100-unit results with the old 10 units, …, and the new 10,000-unit with the old 1,000-unit.

Also compare your transmission line analysis with the new 10,000-unit as well as the old 1,000-unit simulation results.

Think about your observations.

Ongoing project. Stay tuned for next steps.

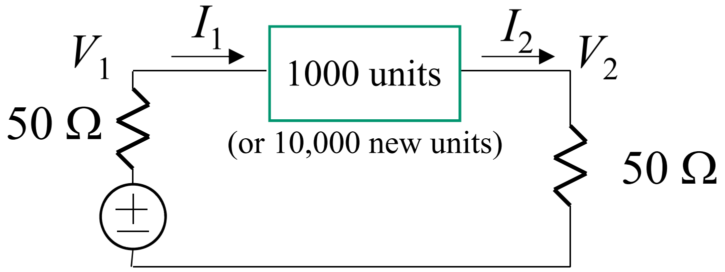


Part 8: Consider the lossless transmission line system (shown above) of **Part 6**. With the step generator replaced by an AC voltage source, do AC analysis manually (actually mentally!) and sketch plots of the following: $\left|\frac{\tilde{V}_2}{\tilde{V}_1}\right|$, phase of $\frac{\tilde{V}_2}{\tilde{V}_1}$, $\left|\frac{\tilde{V}_1}{\tilde{I}_1}\right|$, and phase of $\frac{\tilde{V}_1}{\tilde{I}_1}$, 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 $\Delta\varphi$ be the phase of $\frac{\tilde{V}_2}{\tilde{V}_1}$. Sketch a plot of $\frac{\mathrm{d}}{\mathrm{d}f}\Delta\varphi$ or $\frac{\mathrm{d}}{\mathrm{d}\omega}\Delta\varphi$ 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. (Relate this to Problem 1(2) of Test 1.)



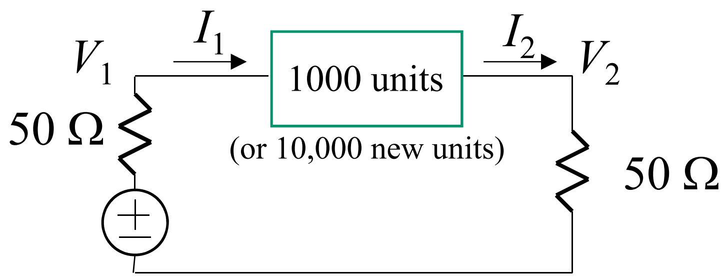
Part 9: Consider the circuit (shown above, with 1000 units for this Part, with $L = 0.3$ nH and $C = 0.12$ pF) of which you did transient simulation in **Part 5**. Do AC simulation and plot the following: $\left|\frac{\tilde{V}_2}{\tilde{V}_1}\right|$, phase of $\frac{\tilde{V}_2}{\tilde{V}_1}$, $\left|\frac{\tilde{V}_1}{\tilde{I}_1}\right|$, and phase of $\frac{\tilde{V}_1}{\tilde{I}_1}$, 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 $\frac{\tilde{V}_2}{\tilde{V}_1}$. Plot $\frac{\mathrm{d}}{\mathrm{d}f}\Delta\varphi$ or $\frac{\mathrm{d}}{\mathrm{d}\omega}\Delta\varphi$ 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 10: Consider the circuit (shown above, with 10,000 units for this Part, with $L = 0.03$ nH and $C = 0.012$ pF) of which you did transient simulation in **Part 7**. Do AC simulation and plot the following: $\left|\frac{\tilde{V}_2}{\tilde{V}_1}\right|$, phase of $\frac{\tilde{V}_2}{\tilde{V}_1}$, $\left|\frac{\tilde{V}_1}{\tilde{I}_1}\right|$, and phase of $\frac{\tilde{V}_1}{\tilde{I}_1}$, 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 $\frac{\tilde{V}_2}{\tilde{V}_1}$. Plot $\frac{\mathrm{d}}{\mathrm{d}f}\Delta\varphi$ or $\frac{\mathrm{d}}{\mathrm{d}\omega}\Delta\varphi$ against frequency f (or $\omega = 2\pi f$).

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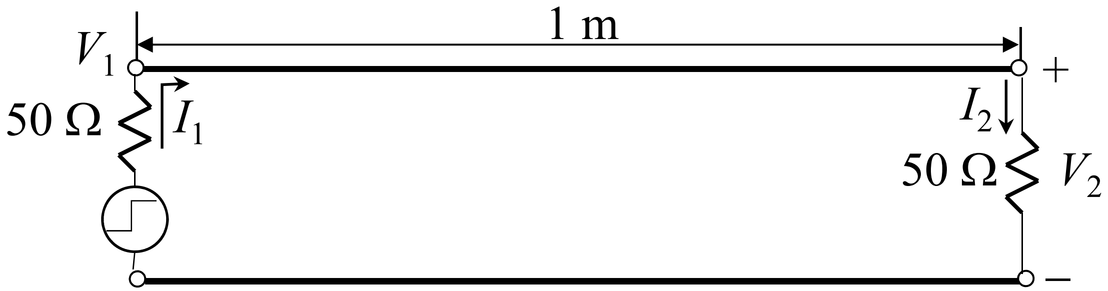

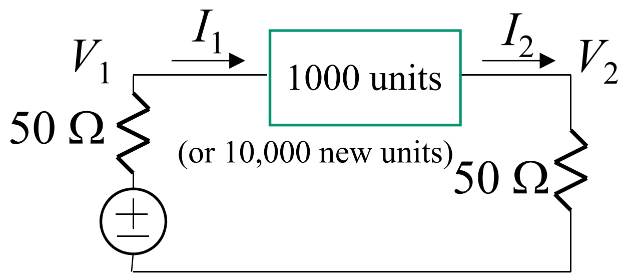

Part 11: Now, quantitatively compare your transient analysis of the transmission line system (above, left) in **Part 6** with the simulation of the circuits (above, right) in **Parts 5 & 7**. What similarities do you observe? What differences do you observe?

To understand the above similarities and differences, compare your AC analysis of the transmission line system in **Part 8** with the circuit AC simulation in **Parts 9 & 10**. 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? Why does the 10,000-unit circuit with L = 0.03 nH and C = 0.012 pF better resemble the transmission line system than the 1000-unit circuit with L = 0.3 nH and C = 0.12 pF? **Hint**: Extra simulations might 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, 9, & 10** 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