Experiment #2: The Step Response of First- & Second-Order Circuits

2.1 Introduction:

Circuits containing energy-storage elements (capacitors and/or inductors) are knows as dynamic circuits. When switching occurs in a dynamic circuit, the circuit response will go through a transition period prior to settling down to a steady-state value. In applications such as data-acquisition, instrumentation, and computer-control systems, the settling time is an important parameter, as circuits must be allowed to settle to steady state before readings are taken.

Dynamic circuits are often characterized by applying a step-function input. The resulting step-response provides important insights into the response of dynamic circuits in general. By investigating the step response, we discover that it consists of a dc-component called the forced response, and a rapidly vanishing time-varying component, called the natural-response. The form of the time function for the natural component depends on the order and composition of the circuit. While the natural response of a first-order circuit is an exponentially-decaying time function, the natural response of a second-order circuit is one-out-of-three possible functions known as over damped, critically damped, and under damped, with the under damped case being an exponentially-decaying sinusoid.

This experiment examines the step response of various first- and second-order dynamic circuits.

2.2 Objectives:

- Demonstrate two approaches that the Multisim circuit simulation software can be used to plot the step response of dynamic circuits.
- Note that the first approach can only be used in simulation. The second approach is the method can be used by an physical (instead of simulated) oscilloscopes to measure the step response of dynamic circuits.
- To measure the parameters that characterize the step response of first- and second-order dynamic circuits.

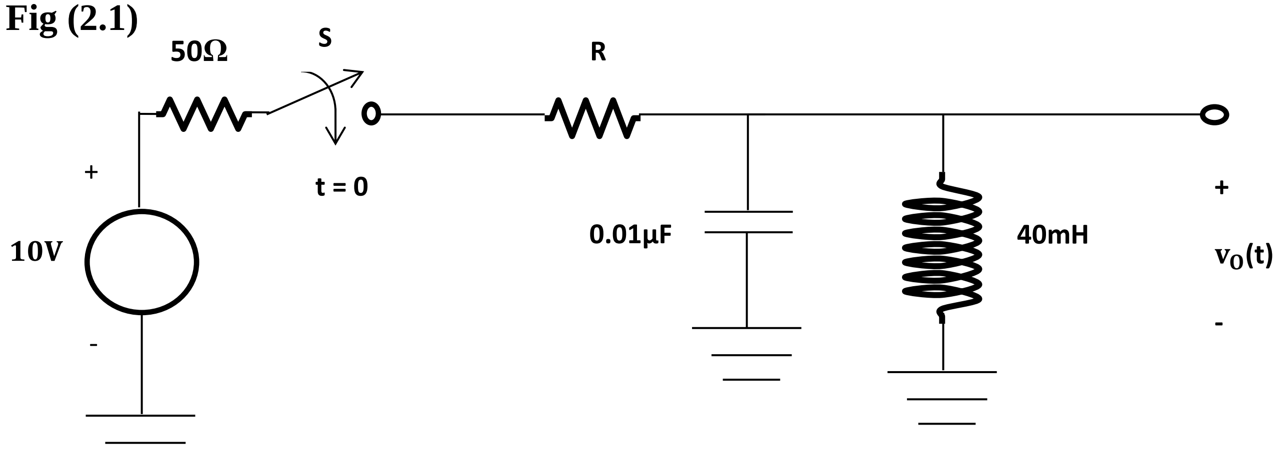
Note: the prelab assignment demonstrates approach 1, which is a simulation only approach. The lab procedure demonstrates approach 2, which can be used both physically and in simulations.

2.3 <u>Prelab Assignment (3 marks in total, 1 mark for each step):</u>

Step 1: Consider the dynamic circuit shown in Fig (2.1). The switch S has been open for a long time. At t=0, the switch is closed, where it remains for a long time.

a) Use Multisim to plot the step response [$v_o(t)$ for t≥ 0^+] when R=1.4kΩ, 3.4kΩ, and 500Ω. Use a STEP_VOLTAGE source to represent the DC power and switch and set its "Final level" to 10 V. Please use an oscilloscope to measure $v_o(t)$ and use "User-defined" setting for "Initial conditions:" under the "Simulate->Analyses and simulation" menu option. Set the End time (TSTOP) to 0.01 s and run the simulation.
b) Locate the transient on the oscilloscope, change the settings to zoom in to the graph, and set the "Y pos. (Div)" to -2. Use the plots to calculate the parameters (σ and ω) that characterize the step response as: $\mathbf{v_o}(t) = A\boldsymbol{e}^{-\sigma t}\sin(\omega t)$ for R=3.4kΩ.
c) Repeat part a) when the inductor is removed from the circuit, with R=3.4kΩ.
d) Use the $v_o(t)$ plot to calculate the parameters (A and τ) that characterize the step response as: $\mathbf{v_o}(t) = A\{1 - \mathbf{e}^{(-t/\tau)}\}$.

Fig (2.1)

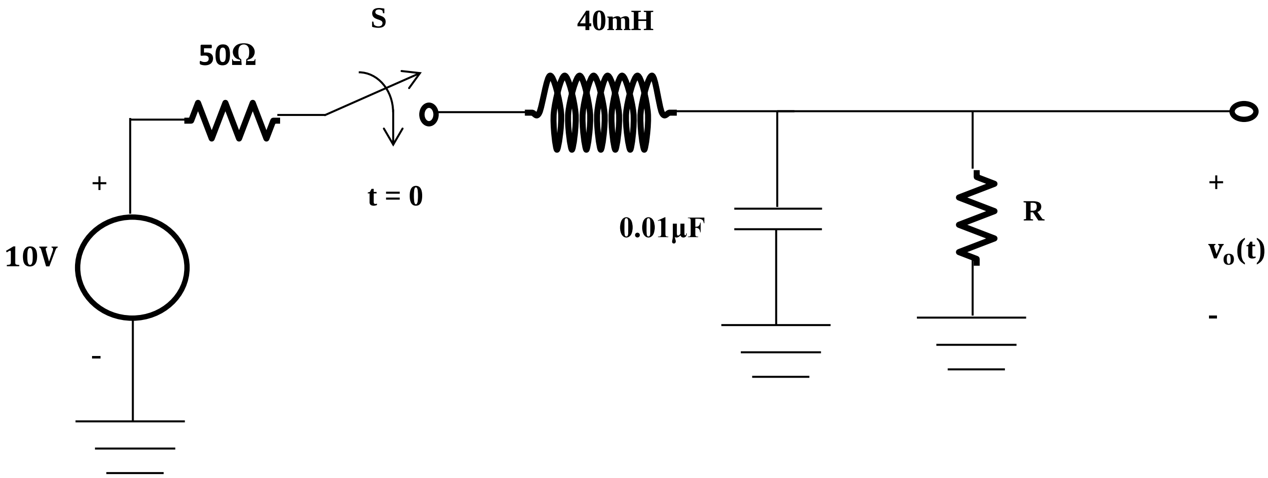


Step 2: Consider the dynamic circuit shown in Fig (2.2). The switch S has been open for a long time. At t=0, the switch is closed, where it remains for a long time.

a) Use Multisim to plot the step response [$v_o(t)$ for t≥ 0^+] when R=1kΩ, 1.4kΩ, and 10kΩ.
b) Use the plots to calculate the parameters (σ and ω) that characterize the step response as: $\mathbf{v_o}(t) = B + A\boldsymbol{e}^{-\sigma t}\cos(\omega t + \theta)$ for R=10kΩ.
c) Repeat part a) when the capacitor is removed from the circuit, with R=1kΩ.

d) Use the $v_o(t)$ plot to calculate the parameters (A and τ) that characterize the step response as: $\mathbf{v_o}(t) = A\{1 - \mathbf{e}^{(-t/\tau)}\}$.

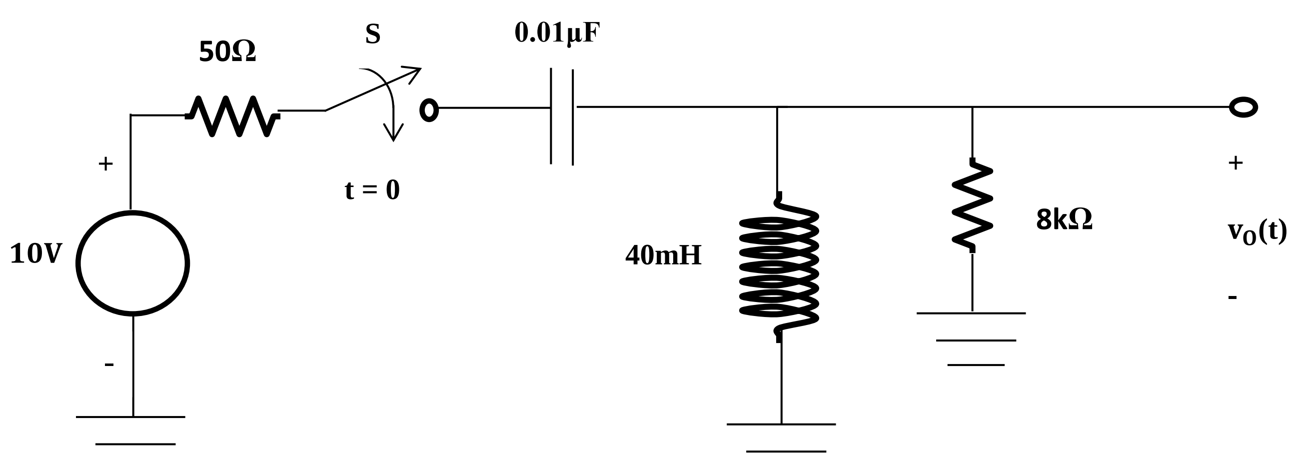
Fig (**2**.2)



Step 3: Consider the dynamic circuit shown in Fig (2.3). The switch S has been open for a long time. At t=0, the switch is closed, where it remains for a long time.

a) Use Multisim to plot the step response [$v_o(t)$ for $t \geq 0^+$].
b) Use the plot to calculate the parameters (σ and ω) that characterize the step response as: $\mathbf{v_o}(t) = A\boldsymbol{e}^{-\sigma t}\cos(\omega t + \theta)$.
c) Repeat part a) when the inductor is removed from the circuit.
d) Use the $v_o(t)$ plot to calculate the parameters (A and τ) that characterize the step response as: $\mathbf{v_o}(t) = A\ \mathbf{e}^{(-t/\tau)}$.

Fig (2.3)



2.4 Procedure:

Part I: The Step Response of a Second-Order Bandpass Circuit

Step 1: Connect Channel (A) of the oscilloscope to display the open-circuit voltage $v_s(t)$ of the function generator. Set the following:

- Trigger: source→Channel (A) and rising edge.

Adjust the controls of the function generator to provide a square-wave signal $v_s(t)$ with a peak-to-peak value of 10V and DC offset of 5V at a frequency of 20Hz and connect the COM port to a reference GROUND.

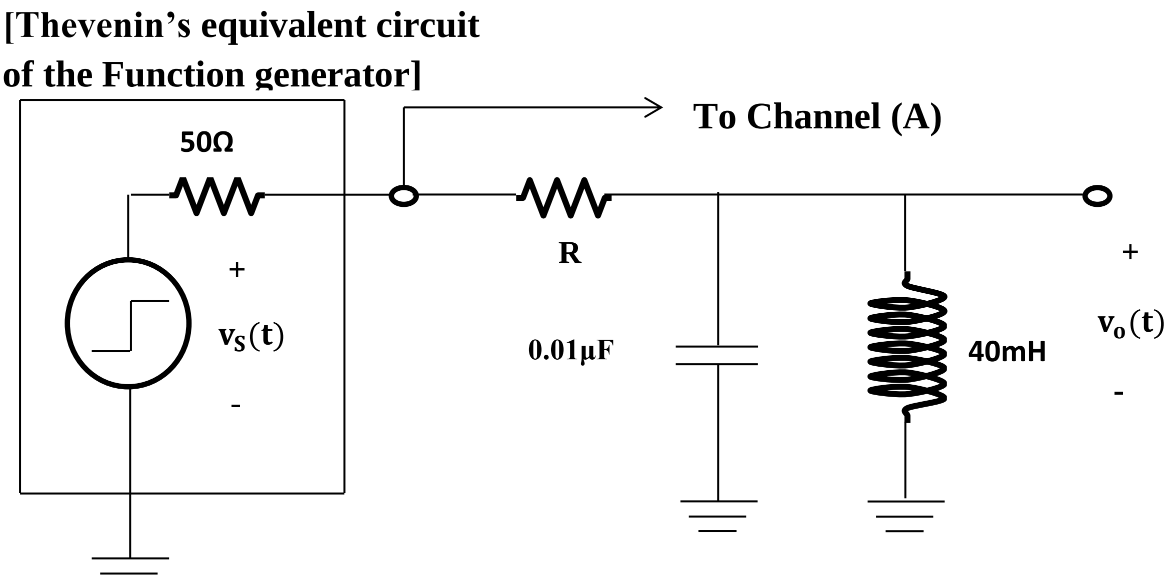
Next, set the following:

- Channel (B): Vertical-position (“Y Pos.(Div)”)→one division above the bottom of the screen, coupling→dc, and Scale→2V/Div.
- Timebase: 50 μs/Div.

Use “User-defined” setting for “Initial conditions:” under the “Simulate->Analyses and simulation” menu option. Set the End time (TSTOP) to 0.1s.

Step 2: Use the RESISTOR_RATED, INDUCTOR_RATED, CAPACITOR_RATED components to construct the circuit shown in Fig (2.4); set R=3.4kΩ. Connect Channel (B) to display the step response $v_o(t)$. Plot $v_o(t)$ on Graph (2.1).

Fig (2.4)



Step 3: Locate a rising transient and use T1 and T2 of the oscilloscope to measure points on the $v_o(t)$ display and to calculate the parameters (σ and ω) that characterize the step response as:

$$\mathbf{v_o}(t) = A\boldsymbol{e}^{-\boldsymbol{\sigma t}}\sin(\omega t) \qquad \text{(Eqn 2.1)}$$

Step 4: Record your result sin Table (2.1) and demonstrate the correct operation of your setup to your TA via ZOOM.

Step 5: Set R=1.4kΩ, and repeat as in Step 2 and Step 3. Record your results in Table (2.1)

Step 6: Set R=500Ω, and repeat as in Step 2.

Step 7: Adjust the value of R back to 3.4kΩ, and remove the inductor from your circuit. Your circuit is now a first-order lowpass circuit. Use Graph (2.2) to plot the resulting step response $v_o(t)$.

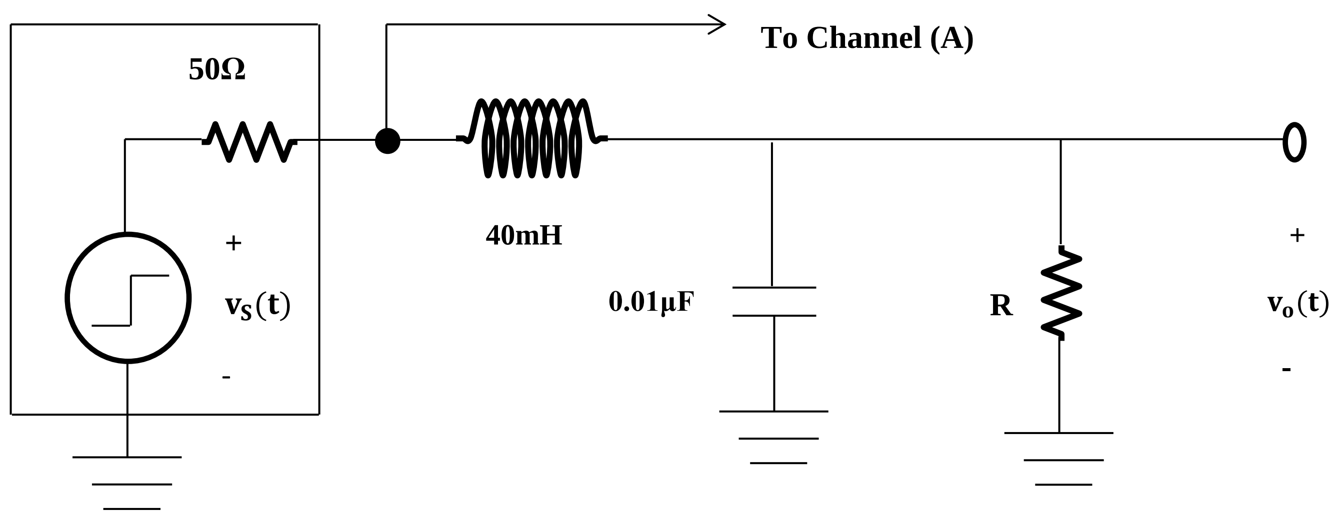
Using the oscilloscope, measure points on $v_o(t)$ display to calculate (and record in Table (2.2)) the parameters (A and τ) that characterize the step response as:

$$\mathbf{v_o}(t) = A\{1 - \mathbf{e}^{(-t/\tau)}\} \qquad \text{(Eqn 2.2)}$$

Part II: The Step Response of a Second-Order Lowpass Circuit

Step 8: Connect the circuit shown in Fig (2.5); set R=10kΩ. Use Channel (B) to display the step response $v_o(t)$ at the bottom of the screen and change the "Scale" to 5 V/Div; plot $v_o(t)$ on Graph (2.3).

Fig (2.5)



Step 9: Locate a rising transient and use T1 and T2 of the oscilloscope to measure points on the $v_O(t)$ display and to calculate (and record in Table (2.3)) the parameters (σ and ω) that characterize the step response as:

$$\mathbf{v_o}(t) = B + A\boldsymbol{e}^{-\sigma t}\cos(\omega t + \theta) \qquad \text{(Eqn 2.3)}$$

Step 10: Set R=1.4kΩ, and repeat as in Step 8.

Step 11: Set R=1kΩ, and repeat as in Step 8.

Step 12: Remove the capacitor from your circuit. With R=1kΩ remaining from Step 11, the circuit is now a first-order lowpass circuit.

Use Graph (2.4) to plot the resulting step response $v_o(t)$.

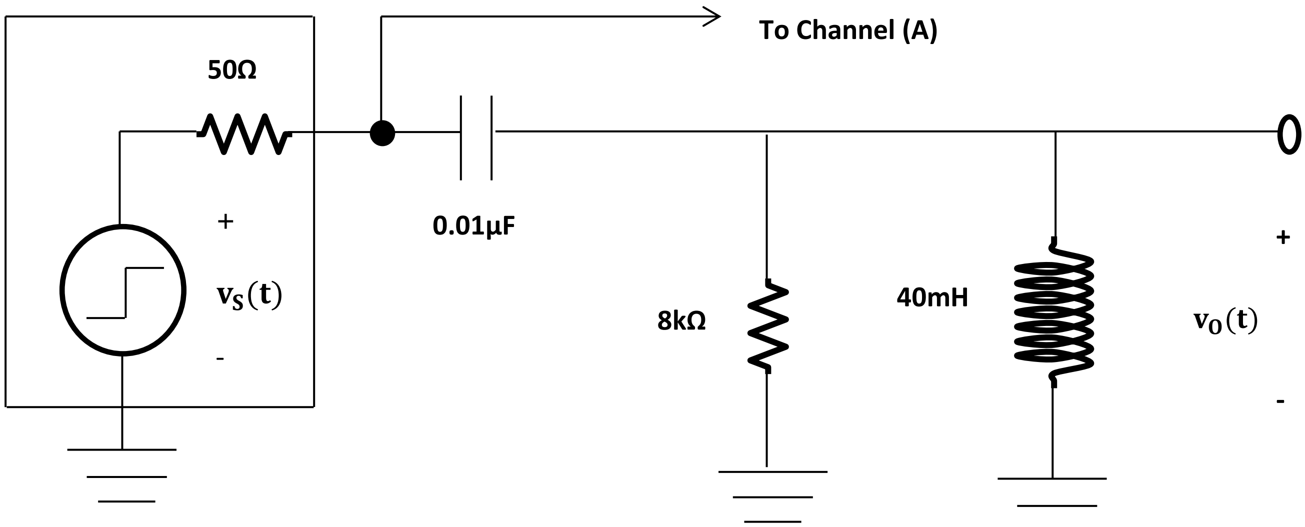
Using the oscilloscope, measure points on $v_o(t)$ display to calculate (and record in Table (2.4)) the parameters (A and τ) that characterize the step response as:

$$\mathbf{v_o}(t) = A\{1 - \mathbf{e}^{(-t/\tau)}\} \qquad \text{(Eqn 2.4)}$$

Part III: The Step Response of a Second-Order Highpass Circuit

Step 13: Connect the circuit shown in Fig (2.6). Connect Channel (B) to display the step response $v_o(t)$; for Channel (B), set the Vertical-position ("Y Pos.(Div)")→*two divisions above the bottom of the screen.* Plot $v_o(t)$ on Graph (2.5).

Fig (2.6)



Step 14: Locate a rising transient and use T1 and T2 of the oscilloscope to measure points on $v_o(t)$ display and to calculate (and record in Table (2.5)) the parameters (σ and ω) that characterize the step response as:

$$\mathbf{v_o}(t) = A\boldsymbol{e}^{-\boldsymbol{\sigma t}}\cos(\omega t + \theta) \qquad \text{(Eqn 2.4)}$$

Step 15: Demonstrate the correct operation of your setup to your TA.

Step 16: Remove the inductor from your circuit. Your circuit is now a first-order highpass circuit. Use Graph (2.6) to plot the resulting step response $v_o(t)$.

Using the oscilloscope, measure points on $v_o(t)$ display to calculate (and record in Table (2.6)) the parameters (A and τ) that characterize the step response as:

$$\mathbf{v_o}(t) = A\ \mathbf{e}^{(-\mathbf{t}/\boldsymbol{\tau})} \qquad \text{(Eqn 2.5)}$$