Department of Electrical, Computer, & Biomedical Engineering
Faculty of Engineering & Architectural Science

ELE 202
Laboratory #6

Transient Response of First Order R-C and R-L Circuits

1.0 INTRODUCTION

A circuit is classified as **First Order** when a first order differential equation is required to solve for all of the variables. A first order differential equation is an equation in which the highest derivative, or order, that it contains is the first derivative, i.e., $\mathrm{d}\mathbf{x}/\mathrm{d}\mathbf{t}$ type. Hence, a First Order circuit contains an equivalent **resistor** and only one type of "***storage***" element, either a **capacitor** or an **inductor**, to form **R-C** or **R-L** circuits.

Unlike resistors, which *dissipate* energy in the form of heat when connected to a power source, capacitors and inductors *store* energy which can be retrieved at a later time. When a capacitive circuit is disconnected from a power source, the capacitor will temporarily maintain voltage. Whereas when an inductive circuit is disconnected from the power source, the inductor temporarily maintains current. Another way of saying this is that the voltage across a capacitor or the current through an inductor cannot change abruptly, as the stored energy would require time to readjust to the new conditions. Hence, the response of a circuit immediately after an abrupt change is called the *transient response*.

The *transient* behavior of an R-C or R-L circuit is best understood and observed by applying a **step-input** (voltage or current) to the circuit. The **step response** results in a "*forced-response*" which is what the circuit does when the source is abruptly turned on but with initial conditions set to zero. The "*natural response"* or *"source-free response*" is what the circuit does, including initial conditions, when its power source is abruptly disconnected or suppressed, which causes the capacitor's, or the inductor's, stored energy to be released to the resistor.

The time-constant, usually denoted by the Greek letter, $\boldsymbol{\tau}$ (tau) is the key parameter that characterizes the response to a **step-input** of a First Order circuit or system. This time-constant, $\boldsymbol{\tau}$ gives the time required for the transient response: **(i)** to rise from zero to 63% (or $1 - 1/\boldsymbol{e}$) of its final steady state value as shown in **Figure 1.0a**, or **(ii)** to fall to 37% (or $1/\boldsymbol{e}$) of its initial value as shown in **Figure 1.0b**. Circuits that have a lower value of $\boldsymbol{\tau}$ can rapidly conform to new conditions, whereas those with higher value of $\boldsymbol{\tau}$ take a longer time to reach steady state conditions. Hence, calculating the time-constant is *essential* for a First-Order circuit as it allows for the determination of how long a transient response phase will last.

References: (i) Course Textbook: "*Fundamentals of Electric Circuits*" by C. K. Alexander and M. N. O. Sadiku

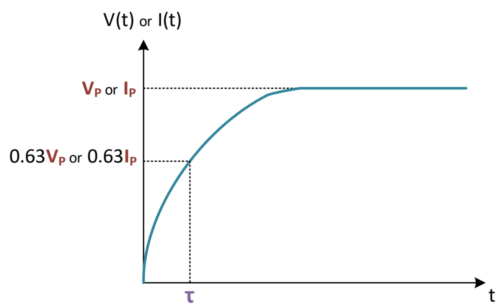


Figure 1.0a: A First-Order "*charging*" transient response

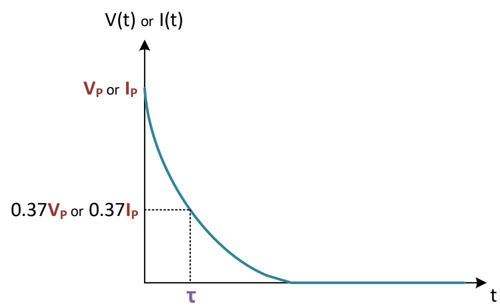


Figure 1.0b: A First-Order "*discharging*" transient response

2.0 OBJECTIVES

- To investigate the **step-input** transient characteristics of First Order **R-C** and **R-L** circuits.
- To understand the concept of the **time-constant**, **τ**.

Note: A repetitive square-wave voltage waveform source will be used to emulate a **step-input** voltage that generates a *forced-response* behavior from the low-to-high transition (**0**v-to-**V**$_P$) during the upper half-period, followed by a **source-free** condition to invoke a *natural-response* behavior from the high-to-low transition (**V**$_P$-to-**0**v) during the lower half-period.

3.0 REQUIRED LAB EQUIPMENT & PARTS

- Digital Multimeter (DMM), Function Generator (FG) and Oscilloscope
- ELE202 Lab Kit:- various components, breadboard, wires and jumpers.

4.0 PRE-LAB: ASSIGNMENT

(a) *R-C Circuit Transient Response*

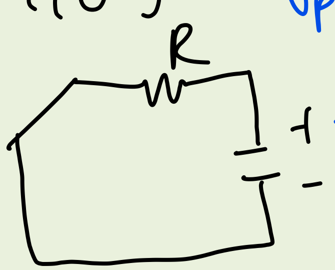
(i) Referring to the **R-C** circuit shown in **Figure 2.0a**, assume the switch has been in position "x" long enough so that the capacitor is fully discharged. At time t = 0, the switch is abruptly moved to position "y" connecting the circuit to the voltage source, thereby creating a step-input voltage of **V_P**. It stays in this position long enough for the capacitor to be fully charged and beyond. Recall, since the voltage across the capacitor does not change instantaneously, then **$V_C(t)$** becomes a more convenient variable to characterize the transient response in the "*charging*" phase than **$I_C(t)$**.

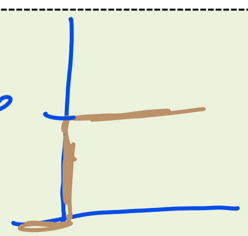
For the above stated conditions, sketch & label the **step-input** response of **$V_C(t)$** and prove that this ***charging*** transient response can be expressed as:

$V_C(t) = V_P(1 - e^{-\frac{t}{\tau}})$ where τ = **RC**

Pre-Lab workspace

$V_c(0^-)$:





$V_c(\infty)$:

discharge

$V_c(\infty) = E = V_p$

$V_c(\infty) + [V_c(0^+) - V_c(\infty)]e^{-t/\tau}$

$V_c(0^-) = 0^V = V_c(0^+)$ $= V_p + (0 - V_p)e^{-t/\tau}$

$= V_p(1 - e^{-t/\tau})$

(ii) For ***each*** set of values of **R** and **C** shown in **Table 2.0**, calculate the corresponding "*charging*" time-constant, τ (*in μsec.*) and steady-state value of $V_C(t)$. Record your results in the appropriate columns. **Note:** 1 *μsec.* = 10^{-6} *sec*.

Pre-Lab workspace

$\tau = RC$
$= 2k\Omega \cdot 0.0047\mu F$
$= 9.4\mu s$

$V_c(t) = V_p(1 - e^{-\frac{t}{9.4\mu s}})$

$V_c(\infty) = V_p(1-0)$
$= V_p$

$\tau = RC$
$= 2k\Omega \cdot 0.015$
$= 30\mu s$

$V_c(t) = V_p(1 - e^{-t/30\mu s})$

$V_c(\infty) = V_p(1-0)$
$= V_p$

(iii) In order to observe the transient response on the MultiSIM or Lab oscilloscope, the **R-C** circuit will be driven with a periodic square-wave signal as illustrated in **Figure 2.1**.

Note: Use of this type of square-wave is equivalent to sequentially "opening" and "closing" the switch in the circuit of **Figure 2.0a**. The period of the square-wave waveform specified would be much longer than the time constant, τ of the circuit to allow the transient response of the circuit to reach its steady state between successive waveform transitions. The upper half of the waveform represents a **step-input** to invoke "***charging***" phase (*forced-response*), while the lower half of the waveform will represent "***discharging***" phase (*natural response*).

To construct and simulate the circuit of **Figure 2.0b** on MultiSIM, use the following procedures to set up the circuit for proper measurements: -

1. Set the function generator (**FG**) for a square-wave output with frequency of **5000 Hz** and $10V_{P\text{-}P}$ voltage, and display the waveform directly on **CH-1** (or CH-A) of the Oscilloscope. Display at least two complete waveform cycles. On the **FG**, apply a **+5V** "DC-Offset" to set the square-wave amplitude from **0v** to **10V** (= V_P), and confirm this on the Oscilloscope display.

2. For **each** set of values provided for **R** and **C** in **Table 2.0**, construct the circuit of **Figure 2.0b** on MultiSIM, connecting the **FG** as the input source signal and using **CH-1** (or CH-A) of the Oscilloscope to monitor this input signal. Simultaneously, display the capacitor voltage, $V_C(t)$ on **CH-2** (or CH-B) of the Oscilloscope. Use proper voltage and time scales on **CH-1** and **CH-2** inputs to adequately display the waveforms over two complete cycles on the scope screen. Capture and record the scope screen signals.
Note: The Oscilloscope inputs (CH-1 & CH-2) should be set for **DC-coupled mode** to retain the critical DC information of the waveforms.

3. From the captured $V_C(t)$ waveform (**CH-2**), determine the values of the time-constant, τ during the "*charging*" and "*discharging*" phases. Refer to the MultiSIM FAQ in D2L on the use of ***vertical*** *and* ***horizontal cursors*** in combination to take reliable measurement of τ from the first-order transient response waveform. Record these results in **Table 2.0** in the appropriate columns.
   - Copy and paste a screenshot showing one MultiSIM readings on the circuit. Include the MultiSIM circuit file (**.ms14**) in your Pre-Lab submission.
   - All screenshots should show your name printed on the center-top of the MultiSIM screen and the timestamp at the bottom-lower corner.

4. Compare and comment on your results in **Table 2.0**, and provide explanation for deviations in the time-constant, τ between the theoretical and MultSIM results. Were the measured time-constants in the "*charging*" and "*discharging*" phases the same? Why?

Pre-Lab workspace

The τs are similar since the time rates are the same, just in different directions. The theoretical & multisim values differed slightly, likely due to rounding & calculation differences.

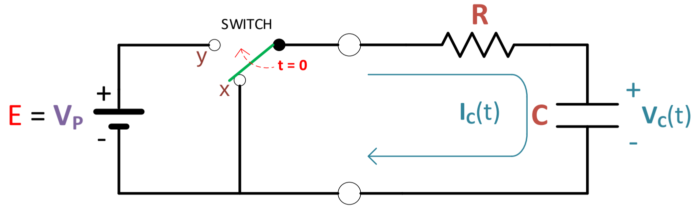


Figure 2.0a: R-C circuit with step voltage source

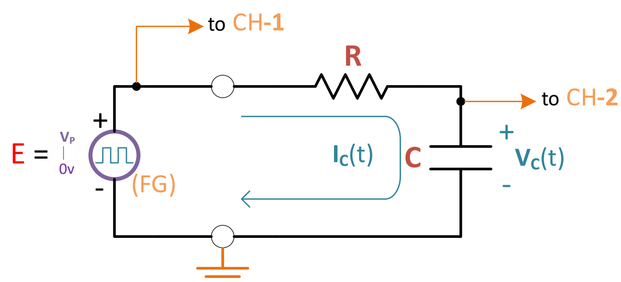


Figure 2.0b: R-C circuit with square-wave input source

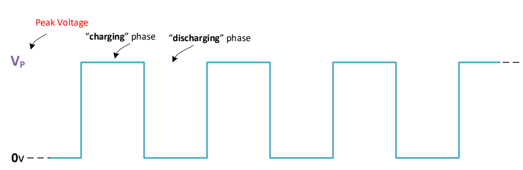


Figure 2.1: Square-wave waveform input voltage source

		Time-Constant, τ			Steady-state value of $V_C(t)$ during "*charging*" phase.	
R	**C**	Theoretical value (*µsec.*)	From MultiSIM result of the "*charging*" phase (*µsec.*)	From MultiSIM result of the "*discharging*" phase (*µsec.*)	Theoretical value (*volts*)	MultiSIM result (*volts*)
2 kΩ	**0.0047 µF**	9.4	9.67	9.78	10	10
2 kΩ	**0.015 µF**	30	29.3	29.35	10	10

Table 2.0: Theoretical and MultiSIM results of the Figure 2.0 circuit

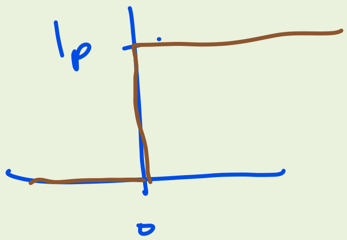
(b) *R-L Circuit Transient Response*

(i) Referring to the **R-L** circuit shown in **Figure 3.0a**, assume the switch has been in position "**x**" long enough so that the inductor is fully discharged. At time t = 0, the switch is abruptly moved to position "**y**" connecting the circuit to the voltage source, thereby creating a step-input voltage of V_P. It stays in this position long enough for the inductor to be fully charged and beyond. Recall, since the current through the inductor does not change instantaneously, then $I_L(t)$ becomes a more convenient variable to characterize the transient response in the "*charging*" phase than $V_C(t)$.

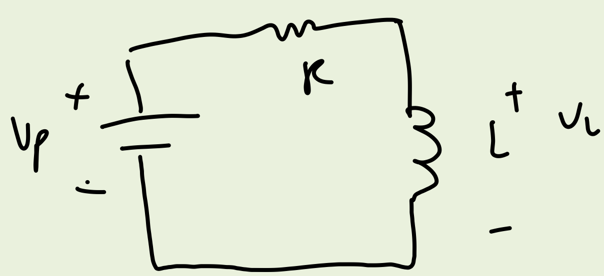
For the above stated conditions, sketch & label the **step-input** response of $I_L(t)$ and **prove** that this ***charging*** transient response can be expressed as:

$I_L(t) = I_P(1 - e^{-\frac{t}{\tau}})$ where $I_P = V_P/R$ and $\tau = L/R$

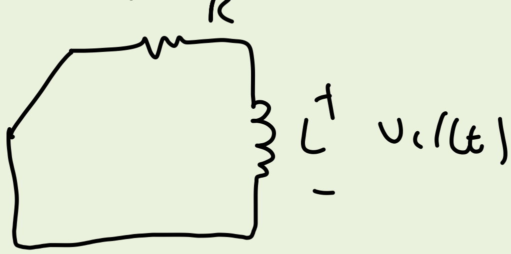
Pre-Lab workspace



$I_L(\infty)$:



$i_L(0^-)$:



discharge

$V_L(0^-) = V_c(0^+) = 0^V$

$V_L(\infty) = V_p$

$\therefore i_L(t) = I_p + (0 - I_p)e^{-t/\tau}$

$i_L(t) = I_p(1 - e^{-\frac{t}{\tau}})$

(ii) For each set of values of **R** and **L** shown in **Table 3.0**, calculate the corresponding "*charging*" time-constant, **τ** (*in µsec.*) and steady-state value of **$I_L(t)$**. Record your results in the appropriate columns. **Note**: 1 *µsec*. = 10^{-6} *sec*.

Pre-Lab workspace

$\tau = L/R$

$= 47mH / 6.2k\Omega$

$= 7.58 \times 10^{-6} s$

$i_L = i_p(1 - e^{-t / 7.58\times10^{-6}})$

$= i_p = V_p/R$

$\tau = L/R$

$= 47 / 2.0k\Omega$

$= 23.5 \times 10^{-6}$

$V_{dt} = \frac{V_p}{R} \cdot 100$

$V_{dt} = 100 i_p$

(iii) In order to observe the transient response on the MultiSIM or Lab oscilloscope, the **R-L** circuit will be driven with a periodic square-wave signal as illustrated in **Figure 2.1**.

Note 1: As noted earlier, use of this type of square-wave is equivalent to sequentially "opening" and "closing" the switch in the circuit of **Figure 3.0a**. The period of the square-wave waveform specified would be much longer than the time constant, **τ** of the circuit to allow the transient response of the circuit to reach its steady state between successive waveform transitions. The upper half of the waveform represents a **step-input** to invoke "***charging***" phase (*forced-response*), while the lower half of the waveform will represent "***discharging***" phase (*natural response*).

Note 2: Because both vertical channels (**CH-1** & **CH-2**) of the oscilloscope need to have one input terminal grounded, all voltage measurements made by the oscilloscope use the ground as a reference and so no unreferenced "differential" voltage measurements (e.g. across **R** in the circuit) are possible using an oscilloscope. Hence, since a current cannot be measured directly with an oscilloscope, then to allow actual monitoring of the current **$I_L(t)$** using voltage measurement, a small "dummy" resistor, **R_d** is placed in series with the inductor, **L** (*in the return path to the ground connection*) as shown in **Figure 3.0b**. This arrangement generates a voltage proportional to **$I_L(t)$** that is monitored on the oscilloscope as **$V_d(t)$** on **CH-2**. It should be noted that as long as **R_d** value chosen is **much less** than **R**, the effect of the resistor **R_d** on the **R-L** circuit's transient responses is negligible, and **can be ignored**. **$I_L(t)$** current values can be determined from the **$V_d(t)$** transient response displayed on **CH-2** using the expression **$I_L(t)$** = **$V_d(t)$/R_d**.

To construct and simulate the circuit of **Figure 3.0b** on MultiSIM, use the following procedures to set up the circuit for proper measurements: -

1. Set the function generator (**FG**) for a square-wave output with frequency of **5000 Hz** and **$10V_{P-P}$** voltage, and display the waveform directly on **CH-1** of the Oscilloscope. Display at least two complete waveform cycles. On the **FG**, apply a **+5V** "DC-Offset" to set the square-wave amplitude from **0v** to **10V** (= **V_P**), and confirm this on the Oscilloscope display.

2. For **each** set of values provided for **R** and **L** in **Table 3.0**, construct the circuit of **Figure 3.0b** on MultiSIM, connecting the **FG** as the input source signal and using **CH-1** of the Oscilloscope to monitor this input signal. Simultaneously, display the voltage, **$V_d(t)$** on **CH-2** of the Oscilloscope. Use proper voltage and time scales on **CH-1** and **CH-2** inputs to adequately display the waveforms over two complete cycles on the scope screen. Capture and record the scope screen signals.
Note: The Oscilloscope inputs (CH-1 & CH-2) should be set for **DC-coupled mode** to retain the critical DC information of the waveforms.

3. From the captured **$V_d(t)$** waveform (**CH-2**) representing **$I_L(t)$**, determine the values of the time-constant, τ during the "*charging*" and "*discharging*" phases. Refer to the MultiSIM FAQ in D2L on the use of ***vertical** and **horizontal cursors*** in combination to take reliable measurement of τ from the first-order transient response waveform. Record these results in **Table 3.0** in the appropriate columns.

- Copy and paste a screenshot showing one MultiSIM readings on the circuit. Include the MultiSIM circuit file (**.ms14**) in your Pre-Lab submission.
- All screenshots should show your name printed on the center-top of the MultiSIM screen and the timestamp at the bottom-lower corner.

4. Compare and comment on your results in **Table 3.0**, and provide explanation for deviations in the time-constant, τ between the theoretical and MultSIM results. Were the measured time-constants in the "*charging*" and "*discharging*" phases the same? Why?

Pre-Lab workspace

The slight deviations are due to different rounding & measurement errors. The charging & discharging constents are the same, since the rates of changes were equal in different directions

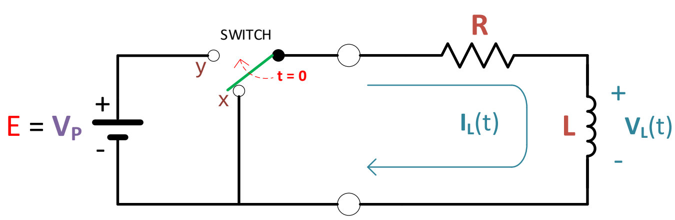


Figure 3.0a: R-L circuit with step voltage source

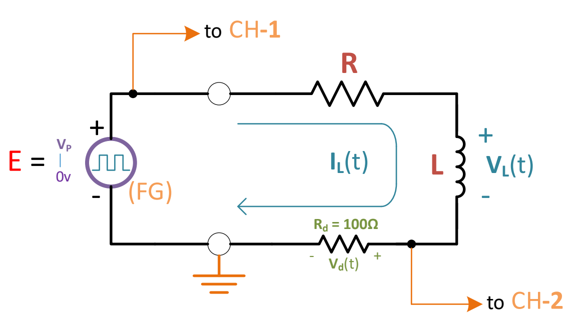
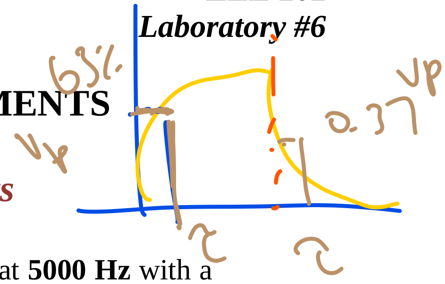


Figure 3.0b: R-L circuit with square-wave input source

		Time-Constant, τ			Steady-state value of $I_L(t)$ during "*charging*" phase.	
R	**L**	Theoretical value (***μsec.***)	From MultiSIM result of the "*charging*" phase **(*μsec.*)**	From MultiSIM result of the "*discharging*" phase **(*μsec.*)**	Theoretical value **(*mA*)**	MultiSIM result **(*mA*)** V.Ch2 div 100 Ω
6.2 kΩ	**47 mH**	7.58	7.5	7.59	0.161	0.189
2.0 kΩ	**47 mH**	23.5	22.76	22.8	0.5	0.471

Table 3.0: Theoretical and MultiSIM results of the Figure 3.0 circuit

*Additional Pre-Lab workspace (**if needed**)*



5.0 IN-LAB Experiment: IMPEMENTATION & MEASUREMENTS

(a) *R-C Circuit Step-Input Transient Response measurements*

1. Set the Function Generator (**FG**) to produce an **10V$_{P\text{-}P}$** square-wave output at **5000 Hz** with a **+5V** "DC-Offset" so that the open-circuit output voltage steps between **0V** and **10V** (= **V$_P$**) as illustrated in **Figure 2.1**. Monitor the **FG** output on **CH-1** of the Oscilloscope to confirm the settings. Set the time-scale on the Oscilloscope to display at least two periods or cycles of the square-wave waveform.
Note: The Oscilloscope inputs (CH-1 & CH-2) should be set to the default **DC-coupled mode** to retain the critical DC information of the waveforms.

2. Construct the circuit in **Figure 2.0b** on your breadboard using the first set of **R-C** values in **Table 2.0**, and set up the appropriate connections to the **FG** and Oscilloscope. Display simultaneously the **FG** source voltage waveform on **CH-1** of the Oscilloscope, and the voltage across the capacitor, **V$_C$(t)** on **CH-2**. Set appropriate vertical voltage-scale for **CH-1** and **CH-2** respectively to ensure both waveforms are optimized for the Oscilloscope display.

3. Once the expected waveforms are correctly displayed, use the Oscilloscope's ***horizontal*** & ***vertical*** "cursors" (or "traces") in combination to reliably measure the time-constant, **τ** during the "*charging*" and "*discharging"* phases of the transient waveform [**V$_C$(t)]** on **CH-2**. Also, observe the steady-state **value** of **V$_C$(t)** towards the end of the "*charging*" phase. Record your measured values of **τ,** and the steady-state value of **V$_C$(t)** in below **Table 4.0**. Freeze the Oscilloscope display to **capture the screen-shot** either by taking picture with your camera or saving the screen image on a USB key, for off-line printing. The captured screen-shots should show the correct time-stamp that was displayed on the Oscilloscope.

4. **Repeat** the above **steps 2** & **3** using the second set of **R-C** values in **Table 2.0.**

For 1st set of **R-C** values >	**τ**$_{\text{"charging-phase"}}$ = 10.4	**τ**$_{\text{"discharging-phase"}}$ = 10.0	**V$_C$(t)**$_{\text{"S-S"}}$ = 10
For 2nd set of **R-C** values >	**τ**$_{\text{"charging-phase"}}$ = 29.0	**τ**$_{\text{"discharging-phase"}}$ = 29.0	**V$_C$(t)**$_{\text{"S-S"}}$ = 10

Table 4.0: In-Lab experiment results of the circuit in Figure 2.0b

(b) *R-L Circuit Step-Input Transient Response measurements*

1. As done earlier, set the Function Generator (**FG**) to produce an **10V$_{P-P}$** square-wave output at **5000 Hz** with a **+5V** "DC-Offset" so that the open-circuit output voltage steps between **0V** and **10V** (= **V_P**) as illustrated in **Figure 2.1**. Monitor the **FG** output on **CH-1** of the Oscilloscope to confirm the settings. Set the time-scale on the Oscilloscope to ***display at least two periods or cycles*** of the square-wave waveform.
   Note: The Oscilloscope inputs (CH-1 & CH-2) should be set to the default **DC-coupled mode** to retain the critical DC information of the waveforms.

2. Construct the circuit in **Figure 3.0b** on your breadboard using the first set of **R-L** values in **Table 3.0**, and set up the appropriate connections to the **FG** and Oscilloscope. Display simultaneously the **FG** source voltage waveform on **CH-1** of the Oscilloscope, and the voltage, **$V_d(t)$** across the "dummy" resistor, **R_d** [reflecting **$I_L(t)$**] on **CH-2**. Set appropriate vertical voltage-scale for **CH-1** and **CH-2** respectively to ensure both waveforms are optimized for the Oscilloscope display.

3. Once the expected waveforms are correctly displayed, use the Oscilloscope's ***horizontal*** & ***vertical*** **"**cursors" in combination to reliably measure the time-constant, **τ** during the "*charging*" and "*discharging"* phases of the transient waveform [**$I_L(t)$**] on **CH-2**. Also, observe the steady-state **value** of **$I_L(t)$** towards the end of the "*charging*" phase. Record your measured values of **τ,** and the steady-state value of **$I_L(t)$** in below **Table 5.0**. Freeze the Oscilloscope display to **capture the screen-shot** either by taking picture with your camera or saving the screen image on a USB key, for off-line printing. The captured screen-shots should show the correct time-stamp that was displayed on the Oscilloscope. **Recall**: **$I_L(t) = V_d(t)/ R_d$**

4. **Repeat** the above steps **2** & **3** using the second set of **R-L** values in **Table 3.0.**

For 1st set of **R-L** values >	$\tau_{\text{"charging-phase"}}$ = 7.4	$\tau_{\text{"discharging-phase"}}$ = 7.4	$I_L(t)_{\text{"S-S"}}$ = 0.1
For 2nd set of **R-L** values >	$\tau_{\text{"charging-phase"}}$ = 22.0	$\tau_{\text{"discharging-phase"}}$ = 23.0	$I_L(t)_{\text{"S-S"}}$ = 0.1

Table 5.0: In-Lab experiment results of the circuit in Figure 3.0b

6.0 POST-LAB: OBSERVATIONS AND ANALYSIS OF RESULTS

1. From your observations of the transient waveforms for the **R-C** circuit from the **Section 5.0(a)** lab experiment, **compare** your measured values of the respective time-constants, τ and the Steady-State value of $V_C(t)_{\text{"S-S"}}$ in **Table 4.0** with the corresponding Pre-Lab and MultiSIM values obtained in **Table 2.0**; and possible causes of errors that may explain any discrepancies.

workspace

The values differ because of scaling and rounding. The experimental osscilliscope scale varied greatly from Multisim's and was difficult to obtain precise values with.

2. From your observations of the transient waveforms for the **R-L** circuit from the **Section 5.0(b)** lab experiment, **compare** your measured values of the respective time-constants, τ and the Steady-State value of $I_L(t)_{\text{"S-S"}}$ in **Table 5.0** with the corresponding Pre-Lab and MultiSIM values obtained in **Table 3.0**; and possible causes of errors that may explain any discrepancies.

workspace

The measured values differed from experimental ones. Discrepancies arised from the awkward scale on the ossilliscope, which made it impossible to take precise measurements, as well as rounding & calculation differences

3. From the waveforms captured for ***either*** **R-C** ***or*** **R-L** circuit, what general observations can be made of the transient response behavior between the two different values of time-constant, **τ** used for each circuit?

workspace

It seems that a larger τ results in a slower responce time and takes longer to reach steady state.

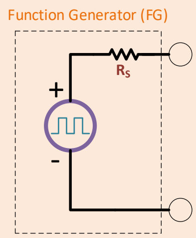
4. In regard to the ***longer*** time-constant, **τ** of ***either*** the **R-C** ***or*** **R-L** circuit, did the transient response (during the "*charging*" phase) reach its final Steady-State value within the first half-period (T/2) of the square-wave waveform? From your observation of the transient responses, what in your estimation is ***minimum*** *multiple* of **τ** (in time) needed for the transient response to almost reach its steady-state value? Explain.

workspace

For the longer time constants, the steady state was not reached within $T/2$. It appears that due to the slow 'charging' of the transiena state, a minimum of $6-7\tau$ is needed to reach steady state.

5. For the **R-C** circuit of **Figure 2.0b**, the Function Generator (**FG**) was assumed to be ideal, meaning that its output (source) resistance, $\mathbf{R_S} = 0\Omega$. In reality, the **FG** has $\mathbf{R_S} = 50\Omega$ as depicted below, and so if one takes this into account then what percentage error does $\mathbf{R_S}$ introduce to the intended (theoretical) time-constants ($\boldsymbol{\tau}$) presented in **Table 2.0**? Can this measurement error be considered negligible? Why?

workspace



2k 0.0047 μF 9.4 10.4

2k 0.015 μF 30 29

$$\left|\frac{10.4-9.4}{9.4}\right| \cdot 100\% = 10.64\%$$

$$\left|\frac{30-29}{29}\right| \cdot 100\% = 3.45\%$$

The measurement errors could be problematic since one of them is quite large

6. For the **R-L** circuit of **Figure 3.0b**, the Function Generator (**FG**) was also assumed to be ideal, meaning that its output (source) resistance, $\mathbf{R_S} = 0\Omega$. In reality the **FG** has $\mathbf{R_S} = 50\Omega$ as noted above. In addition, **(i)** a 'dummy' resistor, $\mathbf{R_d} = 100\Omega$ was introduced in the circuit to facilitate inductor current measurement with the Oscilloscope, and **(ii)** this particular inductor itself has an inherent internal resistance, $\mathbf{R_L} = 162\Omega$; which all add to the overall series resistance of the circuit.
By taking these "additional" series resistances into account, calculate the percentage error introduced in each of your intended (theoretical) time-constants ($\boldsymbol{\tau}$) in **Table 3.0**. Which of the two time-constants ($\boldsymbol{\tau}$) had the largest error, and was this confirmed by your In-Lab results recorded in **Table 5.0**? Explain.

workspace

$$\left|\frac{7.58-7.4}{7.4}\right| \cdot 100\% = 2.43\%$$

$$\left|\frac{23.5-23.0}{23}\right| \cdot 100\% = 2.17\%$$

They all have small errors, but the first R-L set has a larger % error. This is hard to confirm through lab results because both values were still close

7.0 LAB REPORT REQUIREMENTS & GUIDELINES

Lab reporting is to be completed and submitted separately as **Part I** and **Part II**, noted below:

Part I (Pre-Lab Work) => represents **40%** of the pre-assigned Lab weight.

Pre-Lab Work (assignment) of **Section 4.0** that includes handwritten calculations, MultiSIM results, and analysis is to be completed and submitted **prior to the start** of your scheduled lab. *The grading is commensurate with completeness and accuracy of your handwritten calculations, analysis and MultiSIM simulation circuits/plots.*

Note the following requirements for the document submission for Part I:

- A completed and signed "COVER PAGE – **Part I**" has to be included with your submission, a copy of which is available on D2L. The report will not be graded if the signed cover page is not included.
- Your completed handwritten pages of **Section 4.0** should be scanned (via a scanner or phone images), together with the required MultiSIM images. **Note:** *MultiSIM results must be generated using the Department's licensed version of MultiSIM, and the captured screenshots should show your name (at the center-top) and the timestamp (at the bottom-right corner of your screen).*
- Collate and create a .pdf or .docx file of the above, and upload it via D2L **any time prior to the start of your scheduled lab**. Upload instructions are provided on D2L.

Zero marks will be assigned for the entire lab if this Part I is not submitted prior to your scheduled lab.

Part II (In-Lab Work and Post-Lab Work) => represents **60%** of the pre-assigned Lab weight.

In-Lab Work (**Section 5.0**) and **Post-Lab Work** (**Section 6.0**) that include in-lab results, handwritten analysis and observations are to be completed and submitted **by 11.59 p.m.** of the same day as your scheduled lab. *The grading is commensurate with: - completeness, correctness and collection of all experimental results (data and waveforms); merits of observation of the correlations between the experimental and pre-lab assignment results; and reasonableness of the answers to questions posed.*

Note the following requirements for the document submission for Part II:

- A completed and signed "COVER PAGE – **Part II**" has to be included with your submission, a copy of which is available on D2L. The report will not be graded if the signed cover page is not included.
- Scan your completed pages of **Section 5.0** and **Section 6.0** (via a scanner or phone images), together with any required In-Lab Oscilloscope screen-shot images.
- Collate and create a .pdf or .docx file of the above, and upload it via D2L **by 11.59 p.m. on the same day** your lab is scheduled. Late submissions will not be graded.