Ryerson University

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

ELE 202
Electric Circuit Analysis
LAB COVER PAGE for **Part I** submission.

Lab #:	6	**Lab Title:**	Transient Response of First Order R-C and R-L Circuits

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***Signature*:**	

Section #:	11
Submission date and time:	29/3/2023 - 15:00
Due date and time:	29/3/2023 - 15:00

Document submission for Part I:

- A completed and signed "COVER PAGE – **Part I**" has to be included with your submission. 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.

**By signing above, you attest that you have contributed to this submission and confirm that all work you have contributed to this submission is your own work. Any suspicion of copying or plagiarism in this work will result in an investigation of Academic Misconduct and may result in a "0" on the work, an "F" in the course, or possibly more severe penalties, as well as a Disciplinary Notice on your academic record under the Student Code of Academic Conduct, which can be found online at: www.ryerson.ca/senate/current/pol60.pdf.*

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

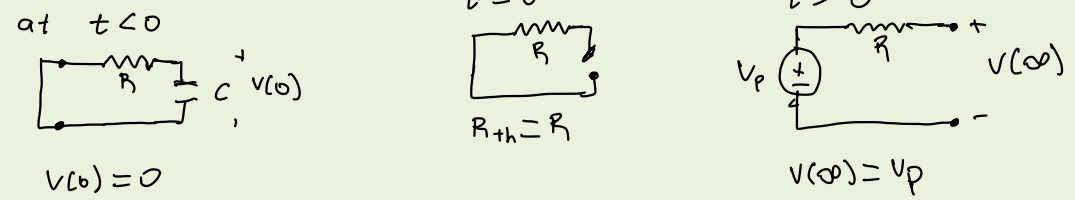
(a) *R-C Circuit Transient Response*

(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:

$$\mathbf{V_C}(t) = \mathbf{V_P}(1 - e^{-\frac{t}{\tau}}) \quad \text{where} \quad \boldsymbol{\tau} = \mathbf{RC}$$

Pre-Lab workspace



$\tau = R_{th} \times C = R \times C$

$V_c(t) = V_\infty + (V(0) - V(\infty))\, e^{-t/\tau} \rightarrow V_c(t) = V_P + (V(0) - V_P)\, e^{-t/\tau}$

$\tau = R \times C$

(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

$\tau = RC$
$= 2 \times 0.0047$
$= 2000 \times 0.0047$
$= 9.4\ ms$

$\tau = RC$
$= 2 \times 0.015$
$= 2000 \times 0.015$
$= 30\ ms$

t at steady state is $5 \times \tau$
$t = 5 \times 9.4\ ms = 47$
$t = 5 \times 30\ ms = 150$

$V_c(t) = V_p + (V(0) - V_p)\, e^{-t/\tau}$
$V_c(t) = 10 + (0 - 10)\, e^{-47/9.4}$
$V_c(t) = 9.93\ V$

$V_c(t) = 10 + (0 - 10)\, e^{-150/30}$
$V_c(t) = 9.93\ V$

(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 **10$V_{P\text{-}P}$** 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

deviations in the time constant τ between theory and multisim are the circuits being different and the theory uses Ideal components whereas multisim does not. the measured time constants in the charging and discharging phases are similar this is because there could be voltage spikes throughout the Graphs.

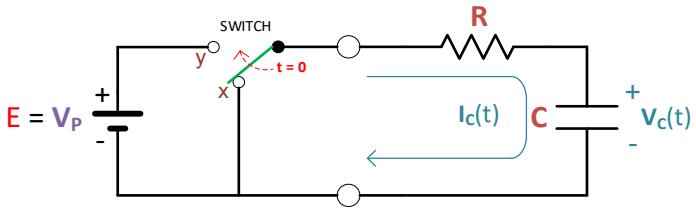


Figure 2.0a: R-C circuit with step voltage source

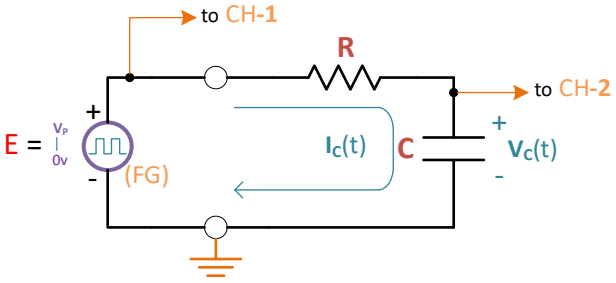


Figure 2.0b: R-C circuit with square-wave input source

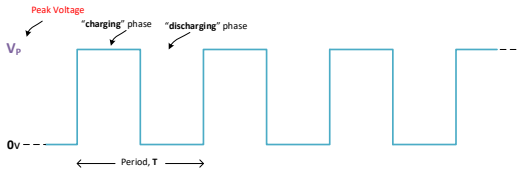


Figure 2.1: Square-wave waveform input voltage source

		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**	9.4µs	9.47µs	9.47	9.93	9.936
2 kΩ	**0.015 µF**	30µs	28.409µs	28.409	9.93	9.673

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

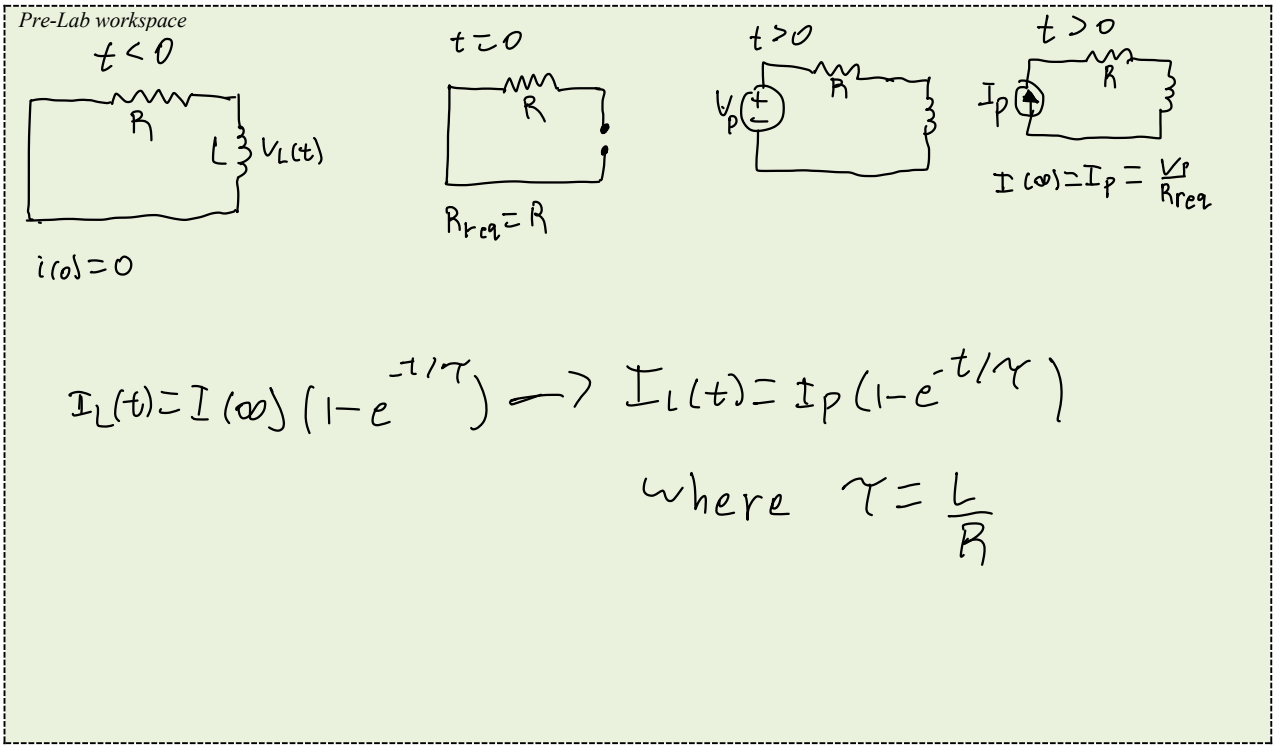
(b) *R-L Circuit Transient Response*

(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



$I_L(t) = I(\infty)(1 - e^{-t/\tau}) \rightarrow I_L(t) = I_p(1 - e^{-t/\tau})$

where $\tau = \frac{L}{R}$

(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

$\tau = \frac{L}{R}$

$\tau = \frac{0.047\,H}{6200\,\Omega}$

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

$\tau = 7.58\,\mu s$

$\tau = \frac{L}{R}$

$\tau = \frac{0.047\,H}{2000}$

$\tau = 2.35 \times 10^{-5}\,s$

$\tau = 23.5\,\mu s$

charging $= t = 5\tau$

$t_1 = 5 \times 7.58 = 37.9$

$t_2 = 5 \times 23.5 = 117.5$

$I_{P_1} = 10/6.2 = 1.613\,mA$

$I_{P_2} = 10/2 = 5\,mA$

$I_L(t)_1 = I_P(1 - e^{-t/\tau}) = 1.613(1 - e^{-37.9/7.58}) = 1.60\,V$

$I_L(t)_2 = I_P(1 - e^{-t/\tau}) = 5(1 - e^{-117.5/23.5}) = 4.96\,V$

(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 **10$V_{P\text{-}P}$** 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.

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   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*** <u>in combination</u> to take reliable measurement of τ from the first-order transient response waveform. Record these results in **Table 3.0** in the appropriate columns.
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Pre-Lab workspace

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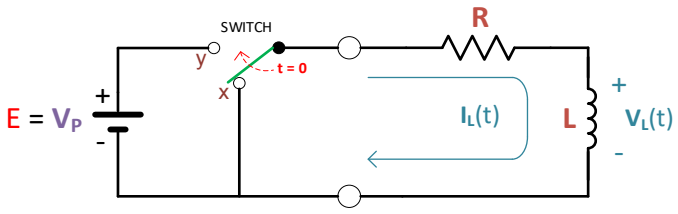


Figure 3.0a: R-L circuit with step voltage source

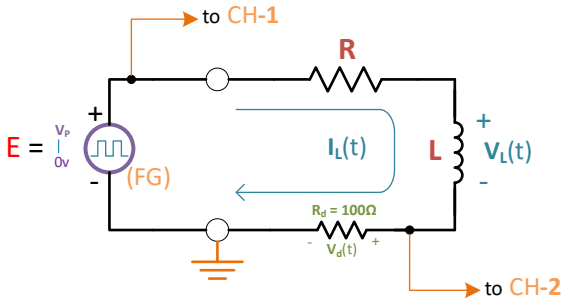
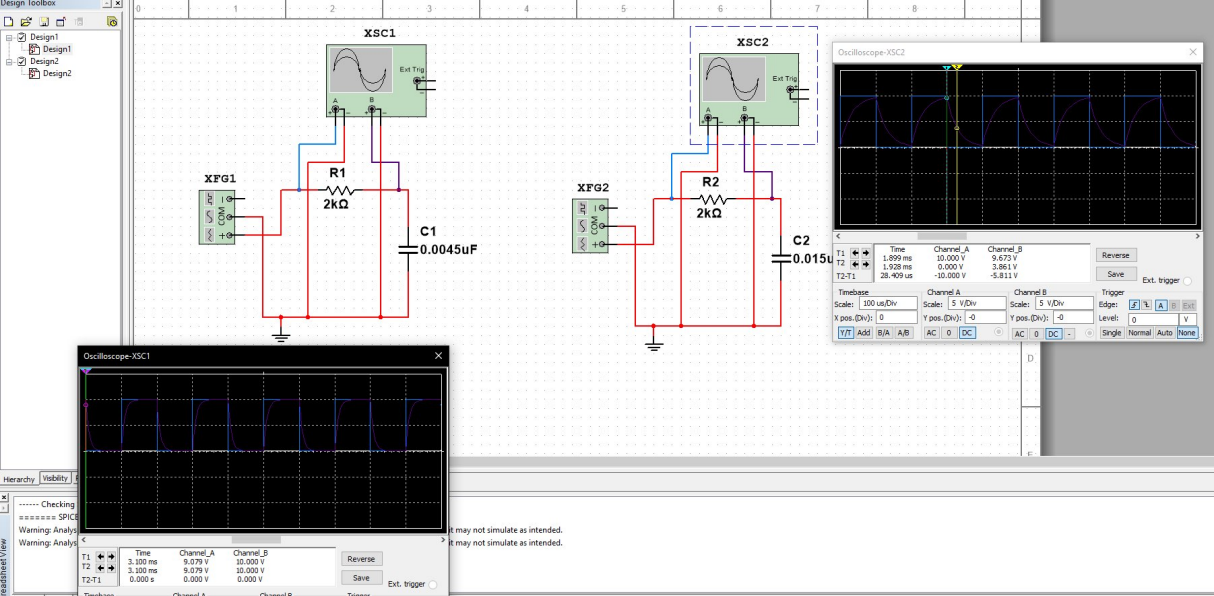


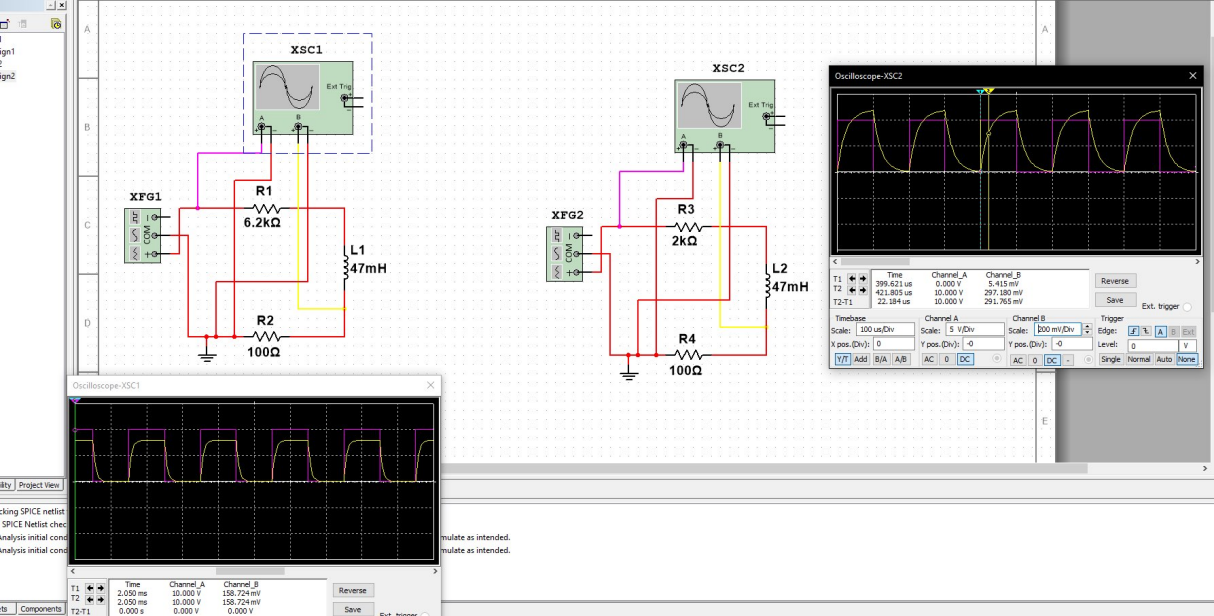
Figure 3.0b: R-L circuit with square-wave input source

		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 (***volts***)	MultiSIM result (***volts***)
6.2 kΩ	**47 mH**	7.58	7.498	7.398	1.6	1.58
2.0 kΩ	**47 mH**	23.5	22.184	23.000	4.96	4.71

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

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


Design Toolbox
Design1
Design1
Design2
Design2
XSC1
Ext Trig
A
B
XSC2
Ext Trig
A
B
XFG1
R1
2kΩ
C1
0.0045uF
XFG2
R2
2kΩ
C2
0.015u
Oscilloscope-XSC2
Time
Channel_A
Channel_B
1.899 ms
10.000 V
9.673 V
1.928 ms
0.000 V
3.861 V
28.409 us
-10.000 V
-5.811 V
T1-T1
Reverse
Save
Ext. trigger
Timebase
Scale: 100 us/Div
X pos.(Div): 0
Channel A
Scale: 5 V/Div
Y pos.(Div): -0
Channel B
Scale: 5 V/Div
Y pos.(Div): -0
Trigger
Edge:
Level: 0 V
Y/T
Add
B/A
A/B
AC
0
DC
Single
Normal
Auto
None
Oscilloscope-XSC1
Time
Channel_A
Channel_B
3.100 ms
9.079 V
10.000 V
3.100 ms
9.079 V
10.000 V
0.000 s
0.000 V
0.000 V
T1-T1
Reverse
Save
Ext. trigger
Hierarchy
Visibility
Checking
SPICE
Warning: Analysis
Warning: Analysis
t may not simulate as intended.
t may not simulate as intended.
Spreadsheet View


XSC1
Ext Trig
A
B
XFG1
R1
6.2kΩ
L1
47mH
R2
100Ω
XSC2
Ext Trig
A
B
XFG2
R3
2kΩ
L2
47mH
R4
100Ω
Oscilloscope-XSC2
Time
Channel_A
Channel_B
T1
399.621 us
0.000 V
5.415 mV
T2
421.805 us
10.000 V
297.180 mV
T2-T1
22.184 us
10.000 V
291.765 mV
Reverse
Save
Ext. trigger
Timebase
Scale: 100 us/Div
X pos.(Div): 0
Channel A
Scale: 5 V/Div
Y pos.(Div): -0
Channel B
Scale: 200 mV/Div
Y pos.(Div): -0
Trigger
Edge:
Level: 0 V
Y/T
Add
B/A
A/B
AC
0
DC
Single
Normal
Auto
None
Oscilloscope-XSC1
T1
T2
T2-T1
Time
Channel_A
Channel_B
2.050 ms
10.000 V
158.724 mV
2.050 ms
10.000 V
158.724 mV
0.000 s
0.000 V
0.000 V
Reverse
Save
Ext. trigger