EXPERIMENT 7:
FIRST ORDER R-L AND R-C CIRCUITS

Objectives:

The objective of this experiment is to observe the response of the first order R-C and R-L circuits. The experiment demonstrates a method for measuring the time constant.

I. BACKGROUND

I.1 Measurement of the Natural Response of First Order Circuits.

The natural response of an R-C circuit, shown in Figure A, is given by (1).

$$v(t) = v_o \cdot e^{-\frac{t}{\tau}} \qquad (1)$$

Where, vo is the value of the capacitor voltage v at t=0s, τ=RC is the time constant of the circuit. The time constant gives the rate at which the voltage decays to zero. In circuits, this decay response is due to ohmic losses.

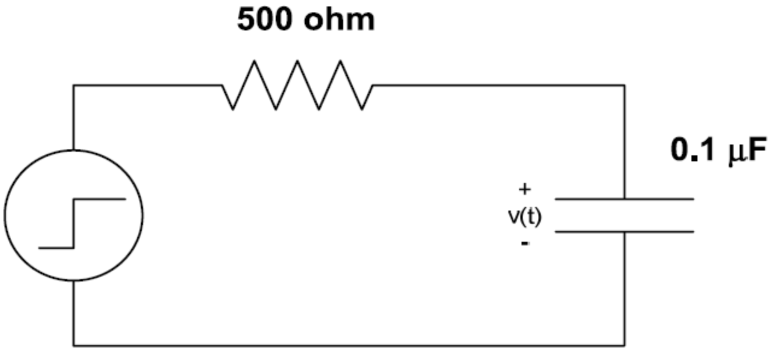

Fig. A. An R-C circuit.

The time constant can be measured by one of the following graphical methods.

(a) The Tangential Line. A line tangential at a certain point of the response curve is drawn. The line intersects the time axis exactly in one time constant from the point of tangent. Figure B shows the graph of the response from (1). Note that the response begins at t= 0.05 s. With reference to Figure B, a line is drawn tangential to the curve at t= 0.05 s (that is at the onset of the decay). The line is extended until it intersects the time axis. This occurs at t= 0.25 s. Therefore, the time constant of the response is

$$\tau = 0.25 - 0.05 = 0.2 \text{ s} \qquad (2)$$

This method is suitable if a hard copy of the response graph is available.

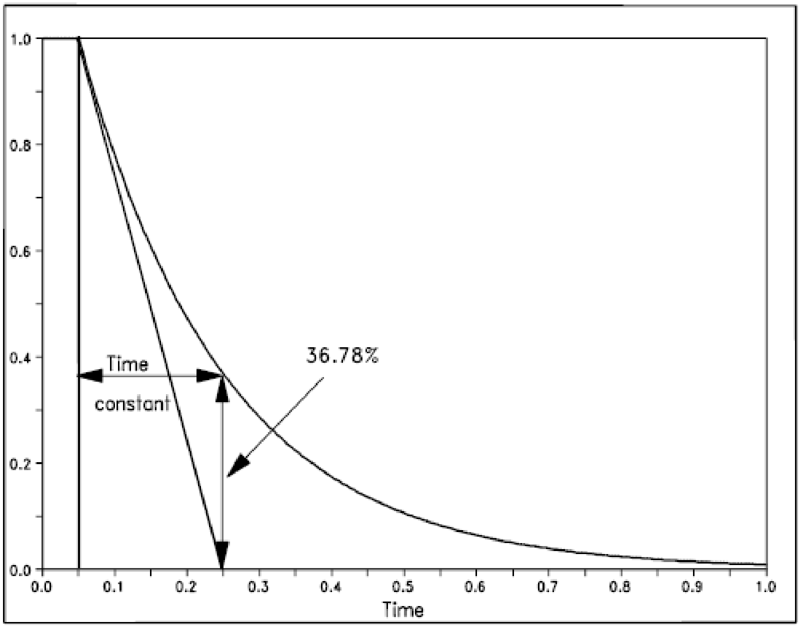

Fig. B. Measurement of the time constant of an exponentially decaying response.

(b) The 63.22% Decay. The second method is suitable for measurements on the oscilloscope. From (1), every time interval equal to one time constant the response decays by 63.22%. Equivalently, at the end of every interval equal to one time constant, the response is at the 100-63.22= 36.78 % of its value at the beginning of the interval. This method of measurement is demonstrated in Figure B. The response begins its decay at t=0.05 s, at that point the value of the curve is 1. The response reaches 36.78 % of its initial value at t= 0.25 s. Thus the time constant is

$$t= 0.25-0.05=0.2 \text{ s} \quad (3)$$

The results of (3) and (2) are in agreement.

I.2 The Step Response of First Order Circuits.
The step response of the first order circuit in Figure A is given by (4).

$$v(t) = v_f\left(1 - e^{\frac{t}{\tau}}\right) \quad (4)$$

Where, v_f is the final value of the response (also, called the constant steady state of the response). The step response of the circuit is characterized by the same time constant as the natural response. The time constant affects the step response in a similar manner as the natural response. Therefore, the methods discussed previously apply in this case, as well.
On the oscilloscope the time constant of the step response can be measured by measuring the time the output requires to reach 63.22% of its final value.

The natural and step responses of a first order R-L circuit, shown in Figure C, are the same as in (1) and (4) given for the circuit current i. The circuit time constant is τ=L/R.

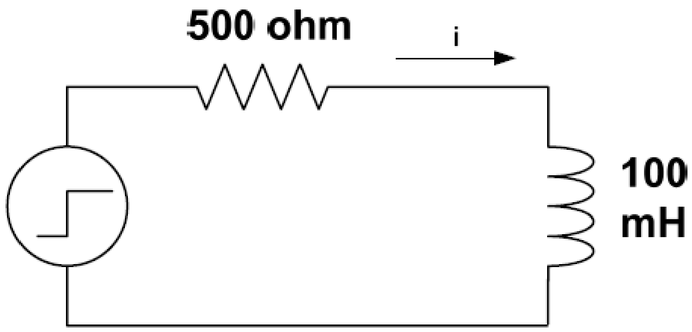

Fig. C. The experimental R-L circuit.

I.3 Oscilloscope Observations.
Non-storage oscilloscopes must display periodic wave forms, so that measurements and observations can be easily made. The natural response of a circuit can be observed along with its step response, if a square-pulse periodic excitation is applied to the circuit.
Figure D shows the response of a first order circuit to a periodic square pulse. The first part of the circuit response is the step response described by (4). The second part of the circuit response, when the excitation becomes zero, is the natural response described by (1). If the response is allowed to decay sufficiently, the following period will begin with another step response followed by the natural response. Thus, the circuit response will alternate between step and natural responses. To achieve good results, therefore, the period of the excitation must be adjusted to 7 to 10 times the time constant of the circuit.

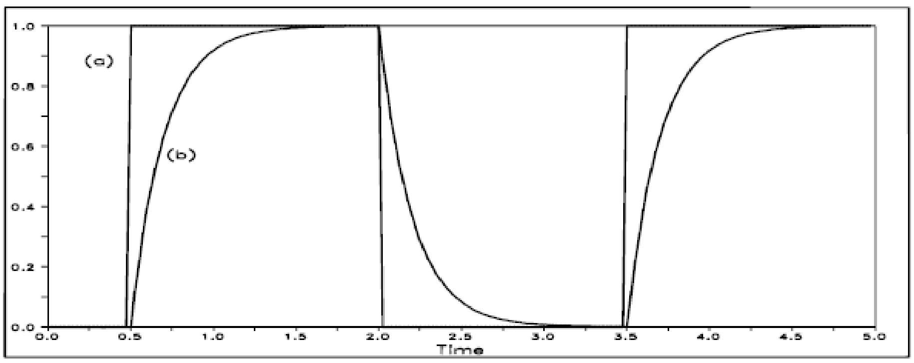

Fig. D. Circuit response to a square pulse excitation with large period. (a) The excitation. (b) The circuit response.

II. INSTRUMENTATION
Function generator, Oscilloscope,

III. PROCEDURE:
Become familiar with the signal generator and the oscilloscope.

- *The R-C Circuit*.

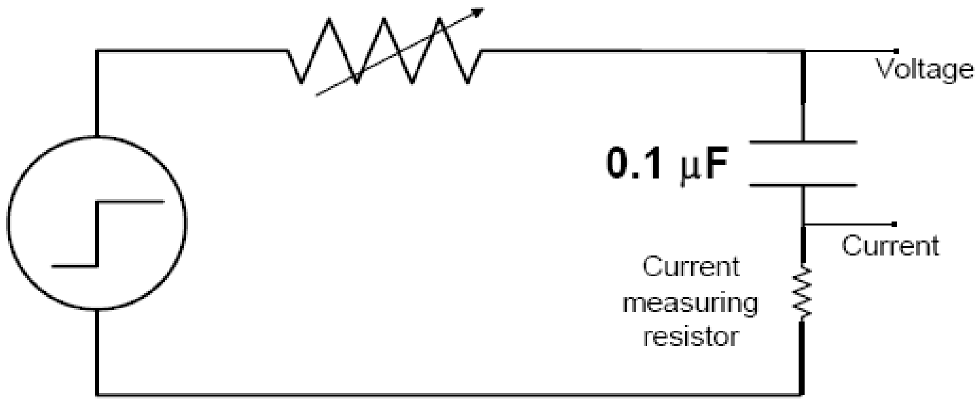

Fig. 1. The experimental R-C circuit.

1. (a) Construct the R-C circuit of Figure 1. Use a **510** Ω.
(b) Apply the square pulse generator to produce a periodic response of the circuit that appears clearly on the oscilloscope. The period of the source is adjusted to be at least 20 times higher than the calculated time constant of the circuit. This is necessary, so that the capacitor reaches steady state, in both charging and discharging intervals. The high level is 10V, and the low level is 0V. The duty cycle is 50%.
(c) Observe on the oscilloscope the quantities shown in the figure. Measure the circuit time constant by the 63% decay method described above.

(d) Take a screen shot of the capacitor voltage and current waveforms, and take a screen shot of the time constant you measured from waveform.
2. Change the resistance in Figure 3 to 250 Ω. Repeat Procedure 1. Do not change the setting of the source.
B. The R-L Circuit.
** Consider internal resistance of the inductor, which is 235Ω, to calculate the time constant.
3. (a) Construct the circuit of Figure 2. Set the resistance box to 510 Ω.
(b) Apply a square pulse voltage. Set the period of the source to 10 times higher than the time constant of the circuit. The high level is 10V, and the low level is 0V. The duty cycle is 50%.
(c) Repeat the same step 1 (c) and (d) for this circuit.
4. Change the resistance to 250 Ω. Repeat.

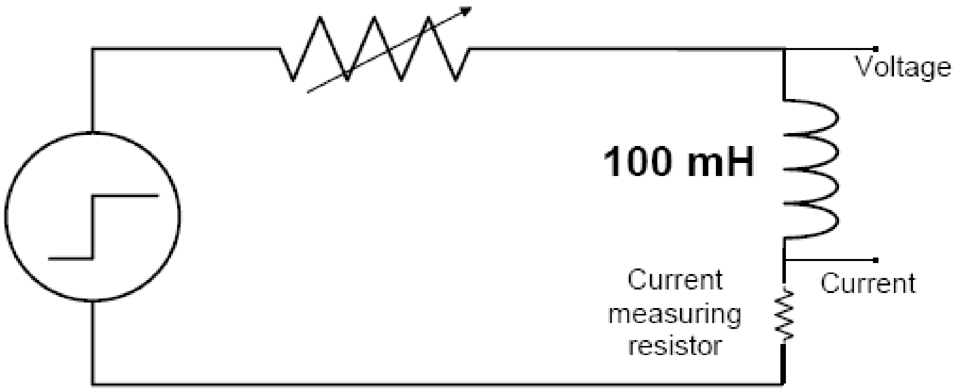

Fig. 2. The experimental R-L circuit.

IV. REPORT
A. Theoretical Development.
1. In theory discuss the natural and step responses of R-C and R-L circuits.
2. Define the duty cycle of a pulse. What is the duty cycle of a square pulse?
3. What is the difference in the setting of x1 and x10 of the oscilloscope probes?
4. How do we adjust the voltage and time scale of the oscilloscope? What is the purpose of calibrating a channel?
5. What is a waveform? What kind of waveforms are best observed and measured by oscilloscopes similar to the one used in the experiment?
6. What is a current measuring resistor? What was the value of the current measuring resistor used in the experiment? Is this value satisfactory?
B. The R-C Circuit.
7. (a) Explain the response observed in Procedure 1. Indicate which interval represents the natural and which interval represents the step response of the circuit.
(b) What is the circuit time constant measured for each value of R?