**University of California, Santa Cruz**
**Baskin Engineering School**
**Electrical Engineering Department**

# Laboratory 3
# Single Time Constant Circuits

EE101L
Intro. to Electronic Circuits Laboratory

## 1. DESCRIPTION AND OBJECTIVE

This laboratory investigates transient voltage and current relationships for single time-constant circuits involving capacitors and inductors. Such circuits when excited by step voltages exhibit exponential responses that will be experimentally observed and analyzed to verify relevant circuit theory.

## 2. GENERAL DISCUSSION

### Capacitors

Capacitors are reactive passive electrical components that store energy. The capacitor *reacts* to a change in its terminal voltage by either sinking or sourcing energy in its electrostatic field. Unless the voltage is changing there is nothing to react to, so there is no current flow and the device looks like an open circuit. Its behavior is governed by the following first-order differential equation:

[1] $$i_c(t) = C\frac{dv_c(t)}{dt}$$

An important physical limitation is that the derivative cannot be infinite; one can't chnge the voltage in zero time (why?). Resistors connected in series or parallel with capacitors form linear *single time-constant* (STC) circuits that obey superposition. When excited by a step change in voltage the capacitor either charges or disharges at a rate proportional to $e^{-t/\tau}$, where $\tau = RC$ is generally known as the *time-constant*. The direction this current flows in a capacitor is important. It is evident by the sign of the derivative and more intuitively summarized in a famous law called *Lenz's Law* that tells us a capacitor will always respond to a change in voltage by generating a current that opposes it. This feature is often used to stabilize voltages across electronic devices by placing *filter capacitors* across these device's power pins.

When driven with a step change in voltage, the response can be quickly determined by the following general equation:

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

$v(\infty)$ is the steady-state value after the exponential has gone to zero, and $v(0)$ is the initial voltage at $t = 0^+$. Note that $v(0)$ accounts for any energy already stored in the capacitor before $t = 0$ when the step change in voltage occurs.

### Inductors

Inductors are also reactive passive electrical components that store energy. The inductor *reacts* to a change in its terminal *current* by either sinking or sourcing energy in its magnetic field. Unless the current is changing there is nothing to react to so there is no voltage across the device and it looks like a short circuit. Its behavior is governed by the following first-order differential equation:

[3] $$v_L(t) = L\frac{di_L(t)}{dt}$$

As with the capacitor the inductor's derivative also physically cannot be infinite; one cannot chnge the current through an inductor in zero time (why?). Resistors connected in series with inductors also form linear *single time-constant* (STC) circuits that obey superposition. When excited by a step change in current the inductor either charges or disharges current at a rate proportional to $e^{-t/\tau}$, where $\tau = L \,/\, R$ is the *time-constant*. The polarity of the reactive voltage across an inductor is important. It too is evident by the sign of the derivative and more intuitively summarized by *Lenz's Law* that tells us an inductor will always respond to a change in *current* by generating a voltage that opposes it. This feature is often used to generate very large transient voltages in such applications as auto ignition. Another way of seeing this is to observe that the sign of the voltage will always be such as to maintain a constant current.

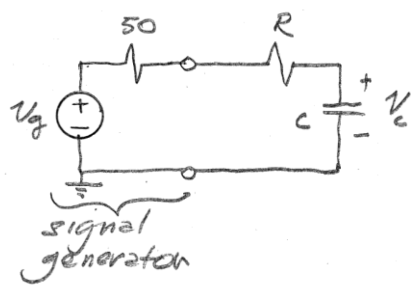
When driven with a step change in current , the response can be determined by the following general equation:

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

## 3. Experimental work

### 3.1 STC RC Integrator

Devise an experiment to display the time-constant charging and discharging curves for the RC circuit shown below. Select appropriate values for R and C so the circuit can be driven with the lab signal generator when set to generate a square-wave (0 to 10 Volts) with frequency sufficient to give the capacitor time to fully charge and discharge every periodic cycle. Carefully observe the voltage directly across the capacitor with the lab oscilloscope and record in your engineering notes for analysis. Verify equation [2] and plot voltage vs. time, accurately determining $\tau$ , $2\tau$ , $3\tau$ , $4\tau$ , $5\tau$ .




### 3.2 STC RC Differentiator

Swap the positions of the resistor and capacitor in the first circuit so you can connect the oscilloscope to observe the voltage across the resistor instead of the capacitor (remember the scope's ground pin is connected to the AC ground, as is the signal generator, so it is incapable of otherwise making floating measurments). Repeat the experiment you did for part 3.1. Discuss why the circuit for 3.1 is called an integrator (or low-pass filter), while the circuit for 3.2 is called a differentiator (or high-pass filter).

### 3.3 STC RL Circuit (extra credit)

If you would like to experiment with an inductor, obtain one from lab staff and see if you can determine its time constant and generally observe waveforms similar to the capacitors. Note that since we cannot drive it with a true current souce, but rather with a step voltage from the lab's signal generator, the current will follow the integral of the voltage.

## 4. REPORT AND SUBMISSION.

Submit a report (see the handout on reporting guidelines; this is posted on our website) discussing the work done in this laboratory.