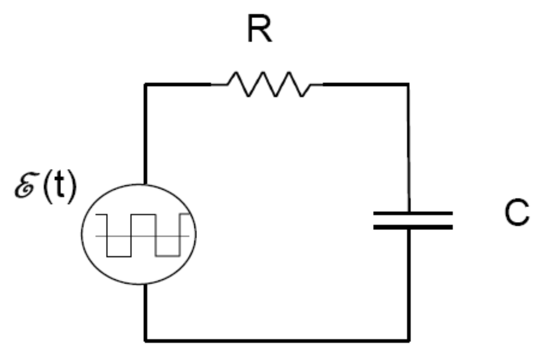
Experiment 2: RC Circuit Transient Behavior

Goal: To learn how to use an oscilloscope and use it to study the transient response of an RC circuit subjected to a square wave EMF applied by a function generator.

Circuit:

The function generator applies an alternating square wave EMF with **amplitude** V_o at frequency f as indicated in the diagram. The voltage waveform across the resistor and capacitor will be measured and compared with theory.



Pre-Lab exercises:

a) Find the time constant for nominal component values $R = 10\ k\Omega, \quad C = 0.03\ \mu F$. What approximate frequency setting f on the function generator would allow for 10 "time constants" of the RC response time to be observed before switching to the opposite polarity of the waveform?

b) Find the potential difference across the capacitor and resistor as a function of time, for both transitions of the square wave, and check that your solutions satisfy Kirchhoff's loop theorem.

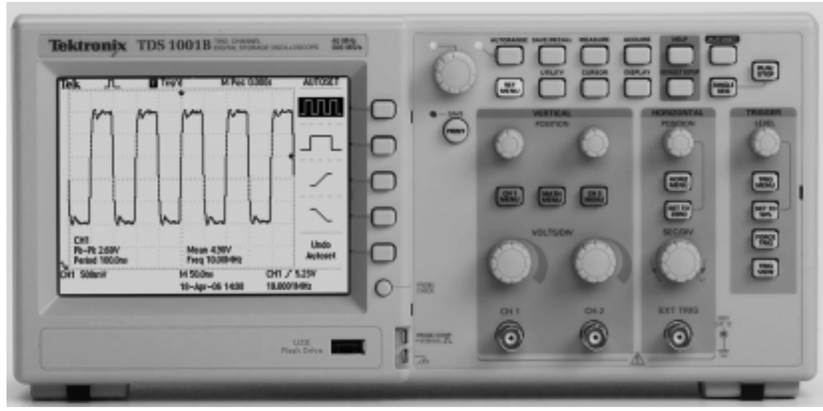
c) Draw a sketch of the expected waveforms for the EMF supplied by the function generator, the potential difference across the resistor, and the potential difference across the capacitor, for a frequency such that each half-cycle corresponds to 4 time constants of the RC circuit. Include at least one full cycle of the square waveform. Draw your diagrams to scale.

d) For the high to low transition, show that the waveform can be simply expressed as $v_C'(t) = v_C'(0)e^{-\frac{t}{RC}}$ where $t = 0$ represents the start of the cycle, and $v_C' = 0$ for $t \to \infty$. What is the value of $v_C'(0)$ in terms of V_0? A graph of ln $\left(\frac{v_C'(t)}{v_C'(0)}\right)$vs t should be a straight line with slope $(-1/RC)$. Note the prime here simply represents another variable, not a derivative.

e) Watch the introductory videos linked to the course web page for this experiment !!!

Equipment:

- Function generator
- Digital oscilloscope and associated circuit probes
- Breadboard Circuit Platform, resistor and capacitor
- Digital multimeter and capacitance meter



Setup:

- Select components with the nominal values $R = 10\ k\Omega, \quad C = 0.03\ \mu F$; measure and record the actual component values. Calculate the time constant of your *RC* series circuit.

- Assemble the circuit using the breadboard, function generator, and leads. Set the function generator to output a square wave voltage signal at a frequency that allows about 3-4 *RC* time constants before changing sign. (This is optimal for studying the detailed time response of the circuit.)

- The function generator amplitude should be set to a few volts. Look carefully at the oscilloscope probe setting and ensure that it is set to "x1". Connect the 'scope probe for channel 1 across the output of the function generator and play around with the controls until you can successfully measure the amplitude and period of the square wave signal.

- Trigger the 'scope on the channel 1 signal and figure out how to adjust the trigger slope and level settings to 'freeze' the display at a particular phase of the square wave cycle.

<u>**Note**</u>: the oscilloscope + probe connection senses the voltage on the center pin relative to ground.

Ground is established on the outer shield of the probe cable via connection to the 'scope chassis. Theory says we can only establish the zero of potential in one place, so take care to connect the probes consistently when you compare channel 1 and channel 2 inputs!

Measurements:

1. Resistor and capacitor waveforms

Attach the second probe to channel 2, and use it to observe the voltage across the capacitor in your circuit, being careful to establish only one ground point in the circuit. Capture the capacitor waveform and print a copy for your report.

Reconfigure the circuit in order to record the function generator signal on channel 1 and the resistor voltage on channel 2. Capture the resistor waveform and print a copy for your report.

Analysis: Test whether Kirchhoff's voltage law is obeyed by this circuit by choosing one particular value of t for the recorded *R* and *C* waveforms, adding the measured potential differences, and comparing with the applied square wave signal.

2. Detailed study: capacitor discharge cycle

Trigger on the falling edge of the function generator signal, display the capacitor voltage on channel 2, and adjust the gain settings until half of one cycle fills the 'scope screen. Capture the waveform for the report.

Use the cursor to measure (t,v_C) for about 8 settings, and then plot the results as described in pre-lab exercise d, and determine the slope from a least squares fit. Compare the fitted slope with the value of RC deduced from the component values.

3. Exploration of frequency dependence:

Start from your frequency setting of part 2, and gradually increase it, noting what happens to the capacitor waveform. Change the vertical scale if necessary. What shape does this take on at very high frequencies? Why?