RC circuits: time and frequency response

RC circuits can be used as frequency filters, which block some frequencies while passing others. In this experiment we will study the properties of RC circuits in the time and frequency domain. We will study these circuits when the input voltages are suddenly applied or removed (transient behavior). If time allows, we will study the response of RC circuits to AC input voltages. An RC circuit is a combination of resistors and capacitors. Figure 1a shows an RC circuit having one resistor and one capacitor in series.

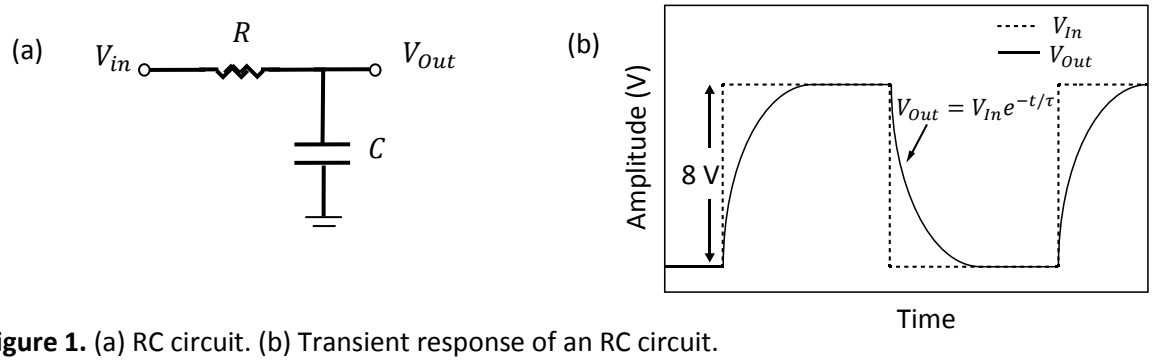

Figure 1. (a) RC circuit. (b) Transient response of an RC circuit.

(I) Transient response of RC circuits to step voltages.

1.- Use your function generator to generate square signals with amplitude of 8 V at a rate of 100 Hz, and observe it in the oscilloscope in channel 1 (CH1) . Use the reference time signal from your function generator, labeled TTL, to trigger the oscilloscope in the "External Trigger" mode. Make sure that your trigger level is not too high or too low, and falls within the voltage range of the TTL signal.

2.- Build the RC circuit shown in Figure 1a, with a resistor of 10 kΩ and a capacitor of 10 nF.

3.-Split your input signal in two by using a "tee", and observe the copy of the signal in channel 2 (CH2). You should see two copies of your square wave in the screen: one in CH1 and the other in CH2.

4.- Use one of the copies as the input voltage V_{In} for the RC circuit, and observe the output V_{Out} of your RC circuit (the voltage across the capacitor) in the oscilloscope. Identify the regions of charge and discharge of the capacitor. (see Figure 1b)

6.- Obtain the RC time constant of your circuit using the oscilloscope and the equation $V_{Out} = V_{In}\exp\left(-\frac{t}{\tau}\right)$ for the decay in voltage as a function of time "t", where τ=RC is the "RC time constant" of your circuit. In a time "t" equal to the RC time constant of your circuit, t=τ, the output signal V_{Out} will drop such that $V_{Out}/V_{In} = \exp(-t/\tau) = \exp(-1) = 0.368$. For example, if your input signal V_{In} has an amplitude equal to 10 volts, V_{Out} will drop to V_{In}*0.368=10*0.368=3.68 volts in a time t=τ. You can use the "CURSOR" function in the top panel of your oscilloscope together with the position knobs to use the cursors to measure time intervals and signal amplitudes.

7.- Compare your measurement of the RC time constant with what you expect from the measured resistance and capacitance.

(II) Frequency response of RC circuits to AC signals.

1.- Change your input square wave to a sine wave, and observe the input and output of your RC circuit.

2.- Position the input and output signals vertically so that the sine waves appear at the center of the oscilloscope screen in the vertical direction.

3.- Use your oscilloscope to do automatic measurements of amplitude of your V_{In} and V_{Out}, and frequency. Go to the "Measure" menu to choose the channel and the specific measurement: amplitude, frequency, etc.

4.-Change the frequency using your function generator from 500 Hz to 4 kHz, and see how the amplitude of V_{Out} changes. This RC circuit is called a low pass filter. Can you tell why?

5.- The cut-off frequency f_c is the frequency at which the input power $P \propto V^2$ drops by half: $P_{Out}/P_{In} = 1/2$. This corresponds to a reduction in voltage where $V_{Out}/V_{In} = 1/\sqrt{2} = 0.7071$. Find the frequency for which your V_{Out}decreases by a factor of 0.7071, which corresponds tof_c, by changing the frequency of your function generator. This frequency relates to the RC time constant as $\tau = 1/2\pi f_c$. Calculate the RC time constant using f_c and compare it with your previous measurements of the RC time constant.

(III) RC circuits to AC signals (2)

1.- Change the configuration of the RC circuit such that V_{In} is connected to the capacitor and V_{Out} is across the resistor as shown in Fig. 2, and analyze the transient response to step input voltages. Draw a diagram similar to the one shown in Fig. 1(b), but now for the response of the RC circuit in Fig. 2. Discuss your observations.

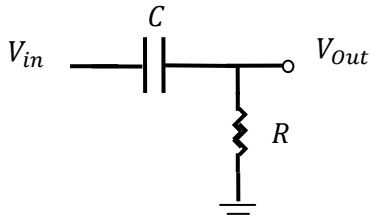

Figure 2. RC circuit (2).

2.-Study the frequency response of this RC circuit by repeating steps from 1 to 4 in section (II) using a sine wave for V_{In} , and observe the output V_{out} of your RC circuit. This RC circuit is called a high pass filter. Can you tell why?

3.- Determine the cut-off frequency of this RC circuit.

4.- Can you think on how to build a band-pass filter with these simple circuits?