Experiment No. 2

RC INTEGRATOR & RC DIFFERENTIATOR

1. OBJECTIVES

** To Understand and verify an integrator (Low pass RC) circuit.

** To Understand and verify a differentiator (High pass RC) circuit.

** To determine the time constant of a circuit.

2. COMPONENTS REQUIRED

** DSO1052B Digital Oscilloscope and Probes.

** Function Generator.

** Capacitor 1 μf.

** Bread Board.

** Connecting wires.

** Resistors 470Ω, 4.7kΩ, 8.2 kΩ, 47 kΩ, 100kΩ.

3. THEORY

A resistor–capacitor circuit (RC circuit), or RC filter or RC network, is an electric circuit composed of resistors and capacitors driven by a voltage or current source.

Time constant of an RC circuit

Time constant of an RC circuit can be measured in two different ways using a digital oscilloscope. The charging and the discharging curves of an RC circuit are shown in the following figure. The time constant theoretically given by $\tau = RC$, is the time taken by the circuit to charge the capacitor from 0 to 0.632 times of the maximum voltage. This can be derived from the charging equation of an RC circuit given in equation 1.

In case of discharging, the time constant is the amount of time required to reduce the voltage across the capacitor from the maximum value to 0.368 of the maximum value. This relation can be derived from equation 2 by replacing t by τ.

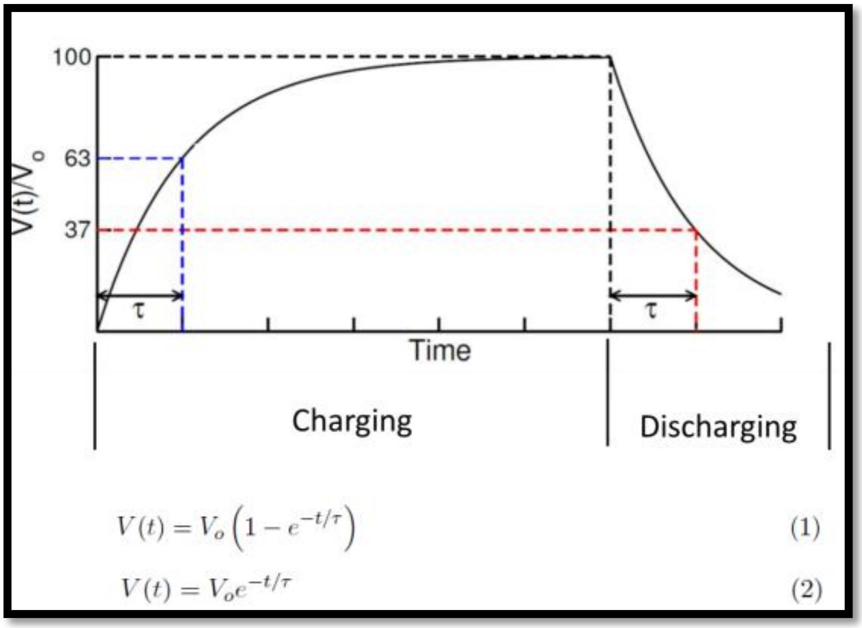


Fig. 1: The capacitor Voltage V_c during the Charging and Discharging.

For a resistor with resistance R in an electrical circuit, the relationship between the applied voltage (V) and the current (I) passing through the resistor is given by Ohm's Law: $V = IR.$ Similarly, for a capacitor with capacitance $C,$ the relationship is $V = IX_c.$ Here X_c is called the capacitive reactance and whose magnitude is defined by $X_c = \frac{1}{\omega C}$. ω is the angular frequency (2πf) of the applied voltage. This is the analog of Ohm's Law for capacitors, and the capacitive reactance is analogous to resistance. So we can use Ohm's law in AC circuits involving capacitors. We notice that for a DC voltage (ω=0) the capacitive reactance is infinite, so no current passes through the capacitor. At low frequencies the reactance is high and at high frequencies the reactance is low. These characteristics can be used to select or reject certain frequencies of an input signal. This selection and rejection of frequencies is called filtering, and a circuit which does this is called a filter.

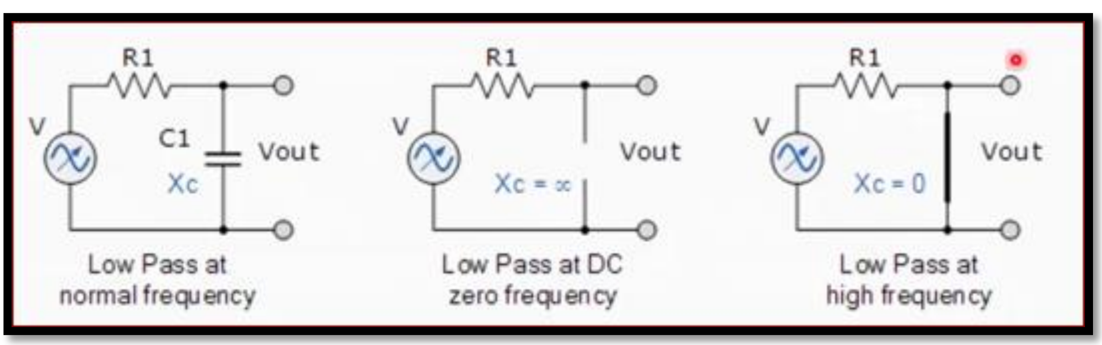


Fig. 2: low pass filter at different frequencies.

What is a filter and why would you ever want to build one?

High and Low Pass Filters

High pass filters are circuits used to remove low frequency signals and allow high frequency signals. Low pass filters do the opposite and are used to remove high frequency signals and allow through low frequency signals.

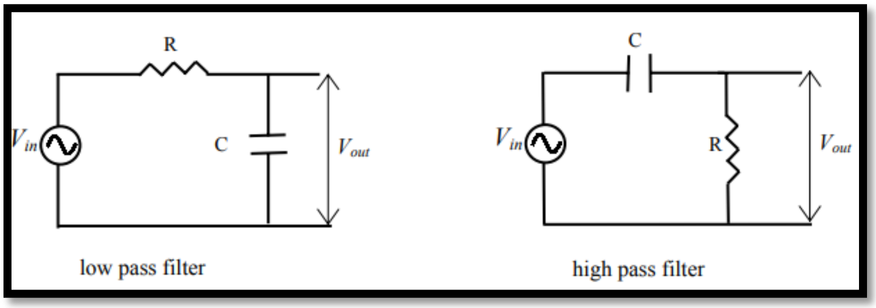


Fig. 3: Low and High Pass Filters.

The circuit on the left in figure 3 is a low pass filter .The low-pass filter allows frequencies below the critical frequency to pass (from dc to fc) and rejects other. The simplest low-pass filter is a passive RC circuit with the output taken across C.

The right hand circuit is a high pass filter. The high-pass filter passes all frequencies above a critical frequency and rejects all others. The simplest high-pass filter is a passive RC circuit with the output taken across R.

The critical frequency of a low-pass *RC* filter occurs when $X_C = R$ where

$$f_c = \frac{1}{2\pi RC}$$

RC Integrator

A circuit in which the output voltage is proportional to the integral of the input voltage is known as integrating circuit. A capacitor is a circuit element whose function is to store charge between two conductors, hence storing electrical energy in the form of a field E(R, t). The process of storing energy in the capacitor is known as "charging", as an equal amount of charges of opposite sign build on each conductor. A capacitor is defined by its ability to hold charge, which is proportional to the applied voltage,

$$\boldsymbol{Q = C\,V}$$

With the proportionality constant **C** called the capacitance. A simple model for a capacitor consists of two parallel conducting plates of cross-sectional area **A** separated by air or a dielectric. The presence of the dielectric does not allow for the flow of DC current; therefore a capacitor acts as an open circuit in the presence of a DC current. However, if the voltage across the capacitor terminals changes as a function of time, the charge accumulated on the capacitor plates is given by:

$$\boldsymbol{q}\ (\boldsymbol{t})\ =\ \boldsymbol{C}\ \boldsymbol{V}\ (\boldsymbol{t})$$

Although no current can flow through the capacitor if the voltage across it is constant, a time-varying voltage will cause charge to vary in time. Thus if the charge is changing in time, the current in the circuit is given by:

$$i\ (t) = \frac{dq(t)}{dt} = \mathrm{C}\ \frac{dv(t)}{dt}$$

The shapes of electrical signals must often be modified to be in a suitable form for operation of circuits. The simple RC circuit often plays a part in the formation of suitable waveforms.

The circuit passes low frequencies readily but attenuates high frequencies because the reactance of the capacitor decreases with increasing frequency. At very high frequencies the capacitor acts as a virtual short circuit and the output falls to zero. This circuit also works as integrating circuit. The condition for integrating circuit is RC value must be much greater than the time period of the input wave (RC >> T).

Let V_i = alternating input voltage and i = resulting current. Applying Kirchhoff's Voltage Law to RC low pass circuit,

$$V_i = iR + \frac{1}{C}\int_0^t i.dt$$

Multiplying throughout by C, we get

$$CV_i = iRC + \frac{1}{C}\int_0^t i.dt$$

as RC >> T, the term, " $\int_o^t$ i dt " may be neglected

$$C\ Vi\ =\ iRC$$

Integrating with respect to T on both sides, we get

$$\int_0^t CVi\ dt = RC\int_0^t i\ dt$$

$$\frac{1}{C}\int_0^t i\ dt = \frac{1}{RC}\int_0^t V_i\ dt$$

$$V_O = \frac{1}{c}\int_0^t i\ dt$$

$$V_O = \frac{1}{RC}\int_0^t V_i\ dt$$

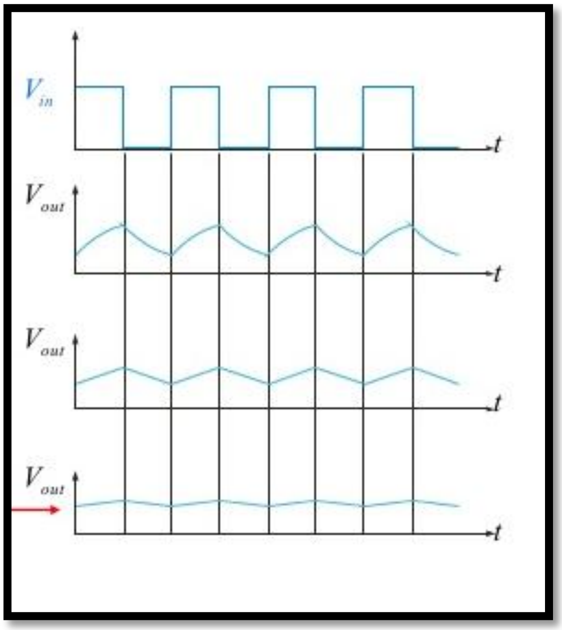
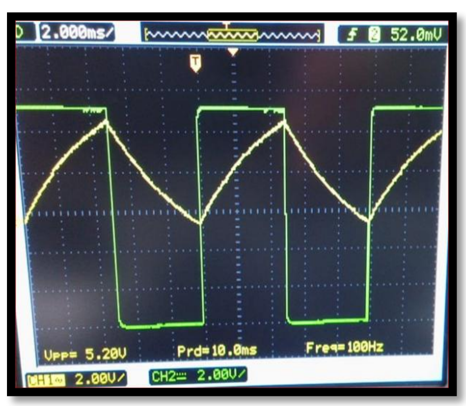
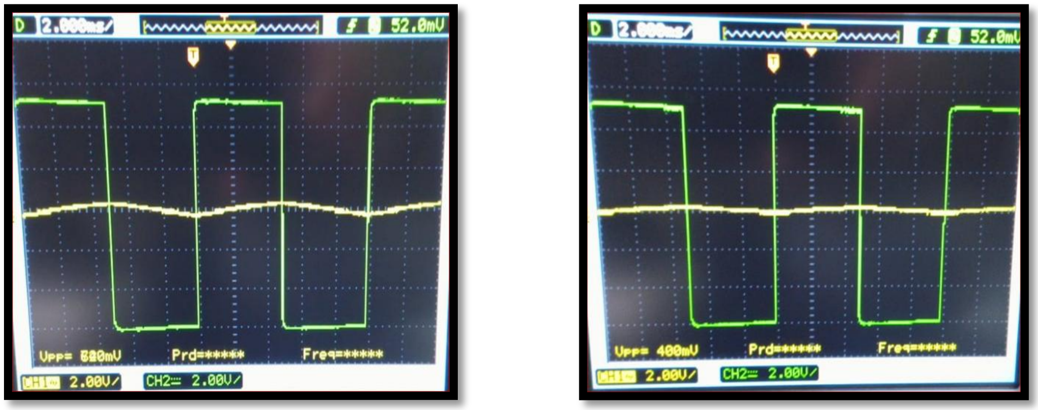


Fig. 4: Output voltage of integrator circuit at different time constant.



$R = 470\ \Omega$ $R = 4.7K\ \Omega$



$R = 47K\,\Omega$ $\qquad$ $R = 100K\,\Omega$

Fig. 5: Output voltage of integrator circuit at different time constant obtained in our lab.

RC Differentiator

The output signal from the differentiator is proportional to the rate of change of the input signal. When the input signal rises or goes positive at the input of the differentiator, the circuit generates a positive going spike. When the input signal falls or goes negative at the input of the differentiator, the circuit generates a negative going spike. When the input is constant or steady the output is zero.

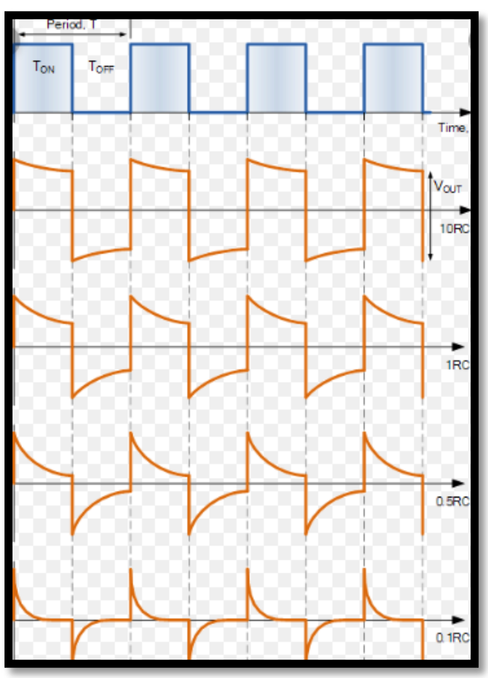
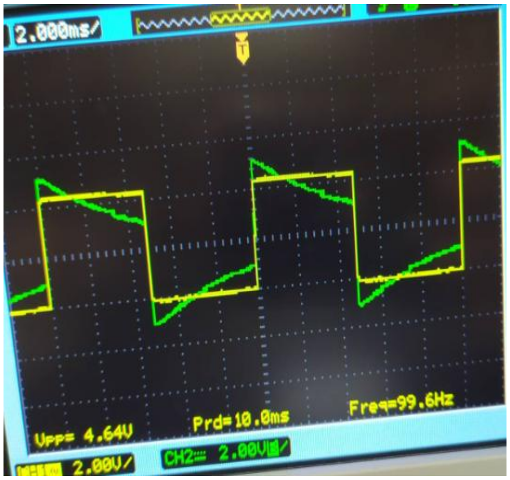


Fig. 6: Output voltage of differentiator circuit at different time constant.



$\boldsymbol{R = 470\ \Omega}$ $\boldsymbol{R = 4.7K\ \Omega}$

Fig. 7: Output voltage of differentiator circuit at different time constant obtained in lab.

4. PROCEDURE

1. Connect the low pass circuit as the circuit diagram (Figure 3).

2. Connect the function generator at the input terminals and CRO at the output terminals.

3. Apply a square wave signal of 6V amplitude and 100 Hz frequency at input.

4. Observe the output waveform of the circuit for different time constants.

Large Time constant ($RC \gg T$), Medium Time constant ($RC = T$), Short Time constant ($RC \ll T$).(this is obtained by changing the value of R)

5. Repeat the above procedure for high pass circuit also (Figure 3).

6. Draw the graph for both low pass and high pass circuits for above three cases of time constants.