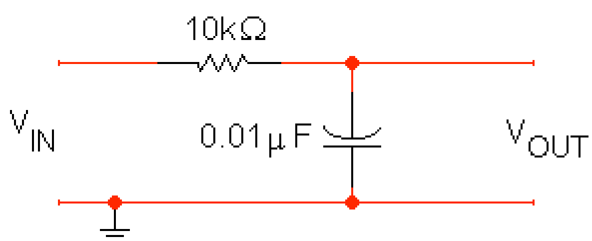
Physics 323

Experiment # 2 - RC Circuits

Introduction

These experiments enable you to re-familiarise yourself with frequency-dependent circuits that rely on the capacitor. The capacitor enables us to make circuits that respond mostly to changes (differentiators) or mostly to averages (integrators), and, by far the most important, circuits that favour one frequency range over another (filters). These circuit elements will be useful later within more complicated circuits. Capacitors are generally easier to include in circuits compared to inductors so we focus on capacitor-based designs.

References *Electronics: A Systems Approach 4e* pp. 79-82, pp. 107-28, pp. 143-168.



(1) RC circuit

Prelab

Give the general expression for the voltage on the capacitor (V_{OUT} on the above circuit) as a function of time, *t,* for two different conditions. (a) V_{IN}=0 but the capacitor starts charged with initial charge Q_0 and voltage $V_0 = Q_0/C$. The capacitor will discharge with time. (b) The capacitor starts with no charge (and no voltage) but at t=0 $V_{IN}=V_0$ (as if a switch were closed at t=0).

What is meant by the time constant for such circuits?

Determine the time constant for the above circuit.

Lab

Construct the circuit above. The DMM has a capacitance option if you are unsure of which capacitor is which but you may need to jumper to the capacitor leads to get to the "slots" on the DMM. The label for the "square" type 0.010 μF capacitor is 103K '10' multiplied by 10^3 pF with a 10% tolerance (the K symbol). The orange capacitors are just labeled 0.01 (I believe the separate '100' indicates a voltage limit.). Drive the circuit with a 500 Hz square wave and look at the input and output with the CRO (using DC input setting). Be careful to just maintain one "ground" in the circuit; the function generator and the oscilloscope are connected to electric outlet ground through their power cords. Measure the time constant by determining the time for the output to drop to 37%. Measure the time to climb from 0% to 63%. Compare with the calculated time constant.

Use this circuit for Part (2).

(2) Integrator

Prelab

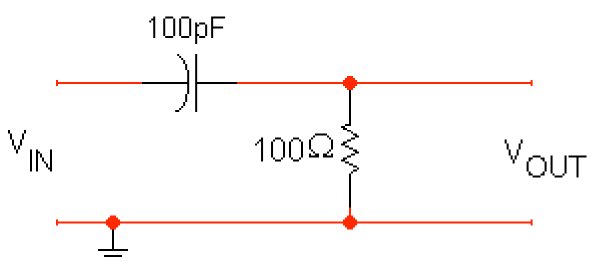
Sketch the waveform you would expect from integrating with respect to time (a) a sine wave; (b) a triangle wave; (c) a square wave.

Lab

Drive the RC circuit from (1) with a 100 kHz wave of square, triangle, and sine shapes and observe. (If the signal is noisy make sure the ground wires of both probes are connected.) Is there a DC component in the output? In the input? Could you envision circumstances where this would be a problem?

Drop the input frequency to ~500 Hz with the square wave. You can now see that "integrating" behaviour is related to the initial response of the RC circuit when the input voltage changes.

(3) Differentiator



Prelab

Sketch the waveform you would expect from differentiating with respect to time (a) a sine wave; (b) a triangle wave; (c) a square wave.

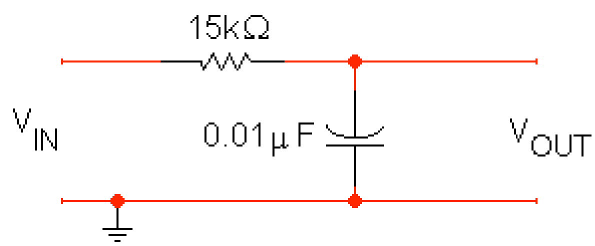
Calculate the frequency $(2\pi RC)^{-1}$. This will separate the low and high frequency regime.

Lab

Construct the RC differentiator shown above. Drive it with a square wave at 100 kHz. Does the output measured on the CRO make sense? Try a 100 kHz triangle wave. Try a sine. Comment on the magnitude of the output versus the input signal.

Now replace the 100 Ω resistor by ~100 kΩ and quickly observe the behaviour of the circuit at 100 kHz. Note that the circuit's characteristic frequency has changed. Obviously this circuit only "differentiates" under certain conditions.

(4) Low-pass Filter



Prelab

What is the value of V_{out}/V_{in} at the 3dB point? (Remember power is proportional to the square of voltage and since this is a passive filter this is really a -3dB point.)

Predict the frequency at the 3dB point, f_{3dB}, for the above circuit. Just a bit of complex number algebra with a voltage divider! (The text calls this f_c.)

What is the phase shift of the output voltage relative to the input voltage (a) at $f = f_{3dB}$; (b) as $f \rightarrow 0$; (c) as $f \rightarrow \infty$. (A phase *lead* is defined to be positive. A *leading* signal will appear to the left when in dual mode on the CRO.)

Sketch the expected frequency response for the amplitude (in dB) and phase of V_{out} compared to V_{in}.

Lab

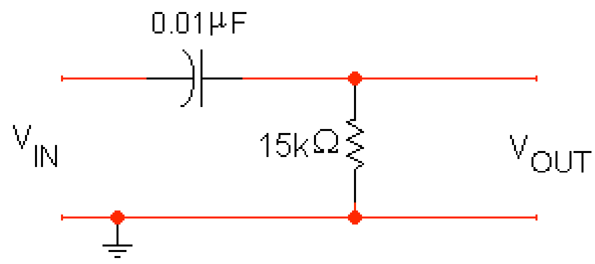
Construct the low pass filter shown above.

Measure the V_{out}/V_{in} ratio and phase at frequencies of 0.1, 0.2, 0.5, 1, 2, 5, 10, 20, and 50 kHz. Drive the circuit with a sine wave. You might also want to use AC coupling on the inputs. You can set the amplitude of the input to whatever you wish but 10 V peak to peak will make the V_{out}/V_{in} ratio easy to calculate. (This set of measurements will take awhile; try your best to stick with it. You might just very quickly change ranges to verify the phase and amplitude behaviour.)

Make plots of V_{out}/V_{in} (in dB) and phase versus frequency (use a logarithmic scale for frequency.)

From your plots find f_{3dB}. Verify that the low-pass filter attenuates 6dB/octave for frequencies well above the 3dB point. (An *octave* is a doubling of frequency. If you have a 6dB drop in power you have a 3dB or halving of the voltage.)

(5) High-pass filter



Prelab

Predict the frequency at the 3dB point, f_{3dB}, for the above circuit.

What is the phase shift of the output voltage relative to the input voltage (a) at $f = f_{3dB}$; (b) as $f \rightarrow 0$; (c) as $f \rightarrow \infty$.

Lab

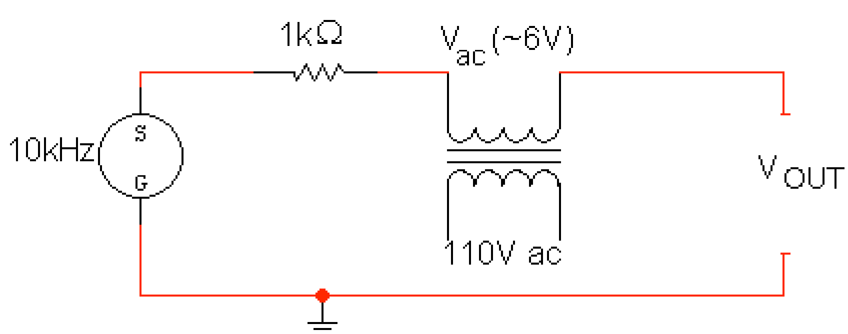
Construct the high-pass filter circuit shown above (just switch *R* and *C* from the previous circuit). Quickly find the circuit's 3dB point.

Check to see if the filter attenuates 6dB/octave for frequencies well below f_{3dB}.

Measure the phase shifts at $f >> f_{3dB}$, $f = f_{3dB}$, $f << f_{3dB}$.

KEEP this circuit!

(6) Selecting signal from signal plus noise



Prelab

Calculate the expected attenuation of a 60 Hz signal for the high pass filter you have saved.

Lab

This circuit will add a high frequency signal from a function generator with a fixed ground to a low frequency (60 Hz) signal provided by a step-down transformer with "floating" inputs. The outside case of the transformer is grounded but none of output terminals are. The middle terminal is a "centre tap" and allows you to just select half of the total voltage.

WARNING: The step-down transformer has a very low internal resistance. If you accidently short circuit it you can get **very large currents** which make the components very hot and create a fire hazard. You also notice the transformers don't have an "OFF" switch. Disconnect the transformer at the output terminals to stop the current.

Build the above circuit and look at output with the CRO. (You might try line-triggering to see the 60 Hz component.) Estimate the relative magntitudes of the 60 Hz and 10 kHz signals. The 1kOhm resistor is for safety. The SG symbol stands for the function generator.

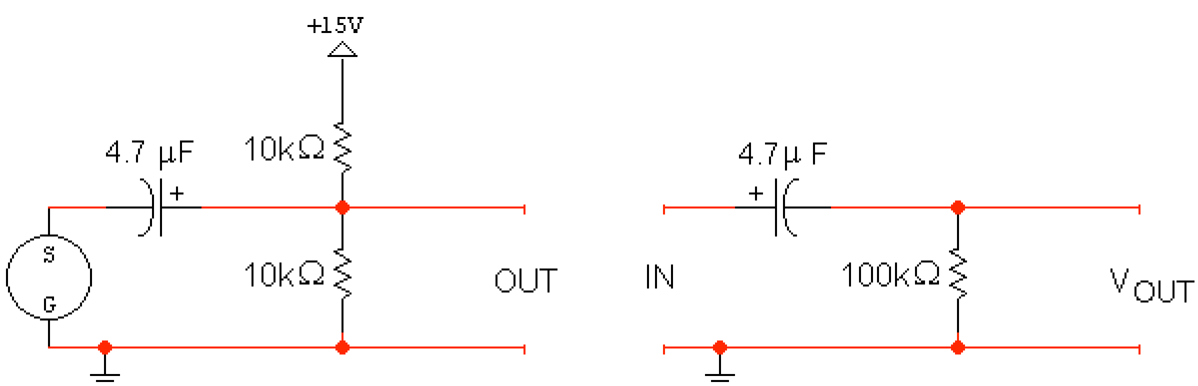
Now run the composite output of the above circuit through the high pass filter and monitor the composite input and final output with the CRO. Is the attenuation of the 60 Hz waveform what you expected?

(7) Blocking capacitor

Prelab

Calculate f_{3dB} for circuit (B).

Google or otherwise look up some info on an electrolytic capacitor. Why do they have a special '+' side?



(A) (B)

Lab

Capacitors are used very often to "block" DC while coupling an AC signal i.e. a high pass filter with all signals of interest well above the 3dB point. Achieving a low 3dB point means you need a relatively big capacitor. The easiest way to do this is to use *an electrolytic capacitor.* These capacitors have one of their leads marked as positive or negative.

Wire up the circuit labeled (A) using a 1 kHz input signal and look at the output on the scope, DC coupled. You should see an AC signal with a DC offset.

Now, add the circuit labelled (B) and observe. Now you can understand how the 'AC' switch on the oscilloscope works. (Compare V_{OUT} from (A) AC coupled to V_{OUT} from (B).)

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