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INTRODUCTION TO ELECTRICAL MEASUREMENTS

Physics 258/259

I. INTRODUCTION

One of the most useful instruments in any laboratory is an oscilloscope. The “scope” enables you to determine the time dependence of a voltage waveform. Thus any time dependent physical phenomena whose characteristics can be converted to a voltage are often measured using an oscilloscope.

II. EXPERIMENTAL METHODS

A. Step response of RC circuit

Construct the RC circuit displayed in Fig. 1. Use channel 1 of the scope to measure the voltage across the capacitor and channel 2 to measure the output of the function generator (oscillator). You can observe both waveforms simultaneously if you set the vertical mode selection to `BOTH` and either `CHOP` or `ALT`. Be sure to use the DC input setting of the scope. (Hint: Use the `TTL` (`SYNCH`) output of the function generator to *externally* trigger the oscilloscope.) Drive the circuit with a 500 Hz square wave and sketch the output (noting all of the vertical gain and horizontal time settings). Measure the time constant by determining the time for the output to drop by 50%. Compare this value to the product $RC/\ln 2$. (Hint: The percent markings over on the left edge of the screen are made-to-order for this task; put the foot of the output signal on 0% and the top at 100%. Then change the time/div

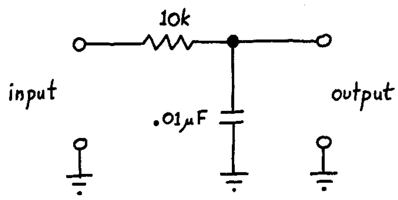

FIG. 1: The circuit layout used to measure the step response of an RC circuit.

(sweep rate) so that you use most of the screen for the fall from 100% to 50%). Measure the time to climb from 0% to 50%. Is it the same as the time to fall to 50%? Measure the value of R with an ohmmeter and compare to the nominal value. You will be given a *mystery capacitor* with an unknown value of C. Determine the value of the capacitance using the circuit above.

B. RC Differentiator

Build the RC differentiator circuit shown in Fig. 2. Drive it with a square wave at 10 kHz, using the function generator with its attenuator set to 20 dB. Sketch the output. Why is this circuit called a differentiator? Try a 10 kHz triangle wave and a 10 kHz sine wave.

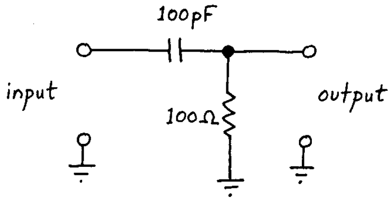

FIG. 2: The RC differentiator circuit.

C. RC Integrator

Construct the integrator shown in Fig. 3. Drive it with a 50 kHz square wave with the attenuator set to 0 dB. Sketch the output. Note what happens as you reduce the frequency to 5 kHz and below.

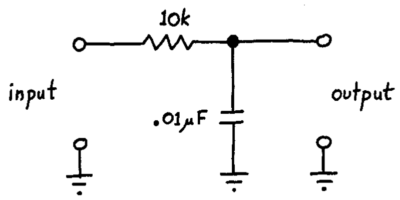

FIG. 3: The RC integrator circuit.

D. RC Low-Pass Filter

Build the low-pass filter illustrated in the Fig. 4. It is the same circuit as you constructed in parts A and C above, but here you will use a different input waveform. Drive the circuit with a sine wave, varying the frequency over a large frequency range in order to observe its low-pass characteristics. The 1 kHz and 10 kHz ranges of the function generator should prove to be the most useful. At very low frequencies, the attenuation factor is 1.0. Determine the frequencies at which the attenuation is 0.8, 0.6, 0.4, 0.2, and 0.1. Find f_{3dB} experimentally by measuring the frequency at which the filter attenuates by 3 dB (0.707 attenuation). Graph the log of the attenuation vs frequency.

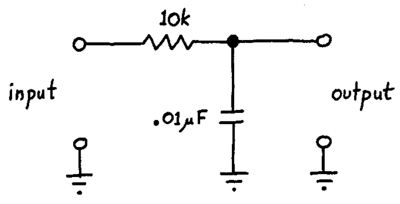

FIG. 4: The circuit layout used to measure the frequency response of an RC low-pass filter.

E. RC High-Pass Filter

Construct the high-pass filter illustrated in Fig. 5. Drive the circuit with a sine wave, varying the frequency over a large frequency range in order to observe its high-pass characteristic. At very high frequencies, the attenuation factor is 1.0. Determine the frequencies at which the attenuation is 0.8, 0.6, 0.4, 0.2, and 0.1. Find f_{3dB} experimentally by measuring the frequency at which the filter attenuates by 3 dB (0.707 attenuation). Graph the log of the attenuation vs frequency.

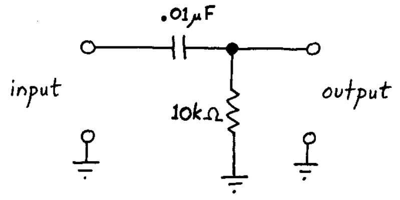

FIG. 5: The circuit layout used to measure the frequency response of an RC high-pass filter.

F. Step response of RL circuit

Construct the RL circuit displayed in Fig. 6. Measure the time constant by determining the time for the output to drop by 50%. Compare this value to the product $L/R \ln 2$. Measure the time to rise from 0% to 50%. Is it the same as the time to fall to 50%? Measure the value of R with an ohmmeter and compare to the nominal value. Determine the value of L from your measurement of $T_{1/2}$ and compare it to the nominal value on the inductor.

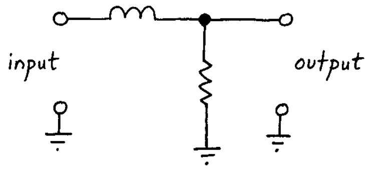

FIG. 6: The circuit layout used to measure the step response of an RL circuit. Use nominal components of $L = 22\,\mathrm{mH}$ and $R = 220\ \Omega$.

G. Phase Measurement

Consider two signals with the same frequency, differing in only amplitude and phase,

$$Y(t) = Y_{max}\sin(\omega t), \qquad X(t) = X_{max}\sin(\omega t + \phi). \tag{1}$$

Both signals have the same frequency but go through zero at different times. This time difference is simply related to the phase angle ϕ. Instead of plotting X vs t and Y vs t, consider Y as a function of X. The graph of X vs Y shown in Fig.7 has the general form of an ellipse. Starting from Eq.(1), **show that**,

$$\phi = \arcsin\left(\frac{X_{int}}{X_{max}}\right). \tag{2}$$

Use the high-pass filter circuit of Fig. 5. Set the function generator to a sinusoidal output. Channel 2 should be used to measure the voltage output of the oscillator and channel 1 to measure the voltage across the resistor. Since $V = IR$, this voltage is simply proportional to the current in the RC series circuit. Set the oscillator for a frequency of 100 Hz. Note that the two signals have a time-offset δt. Use this time offset to measure the phase angle

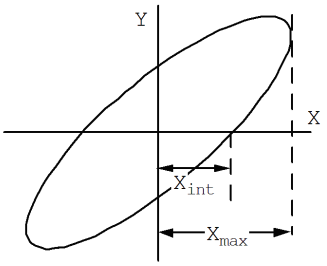

FIG. 7: Lissajous pattern for two sinusoidal signals of the same frequency. Note that X_{int} is the value of X when $Y = 0$.

for frequencies $f = \omega/2\pi = 100$, 200, 500, 1000, 2000, 5000, and 10,000 Hz. Now turn the `SEC/DIV` knob all the way to the left so that it is in the X-Y position. This disables the time sweep circuit so that the horizontal deflection is controlled by the input of channel 1. Adjust the oscillator to a low frequency that is less than 100 Hz. The phase angle at this frequency and RC value is about $\pi/2$. Adjust the `VOLTS/DIV` knob for each channel until the trace looks nearly circular. You may have to twiddle with the vertical and horizontal position knob so that the figure is centered in the oscilloscope screen. Measure the ratio X_{int}/X_{max} and verify that the phase angle between the voltage and current is about $\pi/2$. Measure the phase angle for the following frequencies, 100, 200, 500, 1000, 2000, 5000, and 10,000 Hz. Calculate the phase angle for these frequencies from the values of R and C and compare them with the measured values. Although the capacitor was labeled as $0.01\,\mu$F, what value would you give it based on your phase measurements?