EECE 312 Lab

LAB 4: RC Circuits

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Section 5

Group 9

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I. <u>Objectives</u>:

In this experiment we learned how to:

- Investigate the frequency response and time response of RC circuits.
- Use the oscilloscope to do frequency, time, and phase measurements.

II. <u>Lab Equipment Used</u>:

In this experiment we used:

- The Breadboard
- The Function Generator (HP Agilent 33120A)
- The oscilloscope (Tektronix TDS220)

III. <u>Lab Tools Used</u>:

In this experiment we used:

- Wire Cutter
- Wire Stripper

IV. <u>Components Used</u>:

Component	Theoretical Value	Measured Value	% error
Resistors	1 kΩ, 20 kΩ	0.979 kΩ, 19.851 kΩ	2.1%, 0.745%
Capacitors	0.1 µF, 1 nF		

V. <u>Experimental Procedure and Discussion</u>:

A. Phase Shift Measurements:

A1. Circuit:

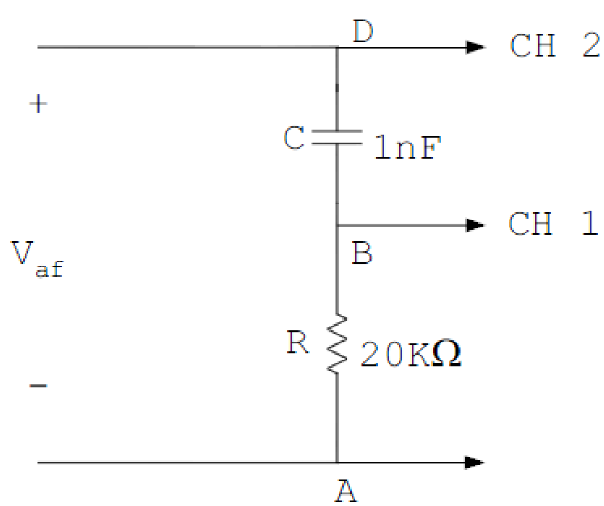


Fig. 1

A2. Detailed Experimental Procedure:

Measure the phase shift between the input voltage and output voltage of the circuit in figure 1 using Y-T format and the X-Y format (Lissajous):

(a) Using the function generator, apply a sinusoidal voltage V_{AF} = 6 V peak-to-peak of frequency 5 kHz to the input of the circuit shown in Fig. 1. Apply V_{BA} to CH 1 of the oscilloscope and V_{DA} to CH 2. Superpose the two traces of V_{BA} and V_{DA} to have the same horizontal axis and adjust the VOLT/DIV and SEC/DIV settings to get stable traces.
Measure the phase difference on the oscilloscope.

(b) Leaving the connections the same as in Part A.1., set the sweep rate to X-Y mode. V_{BA} and V_{DA} will be connected to the X and Y channels of the oscilloscope. An ellipse (called the **Lissajous figure**) will be observed on the oscilloscope screen resulting from the superposition of two perpendicular sinusoidal signals V_{BA} and V_{DA}. Adjust the VOLTS/DIV controls of X and Y and use the vertical and horizontal POSITION knobs to center the ellipse symmetrically as shown in Fig. 2.
Measure 2B and 2A and calculate ϕ.

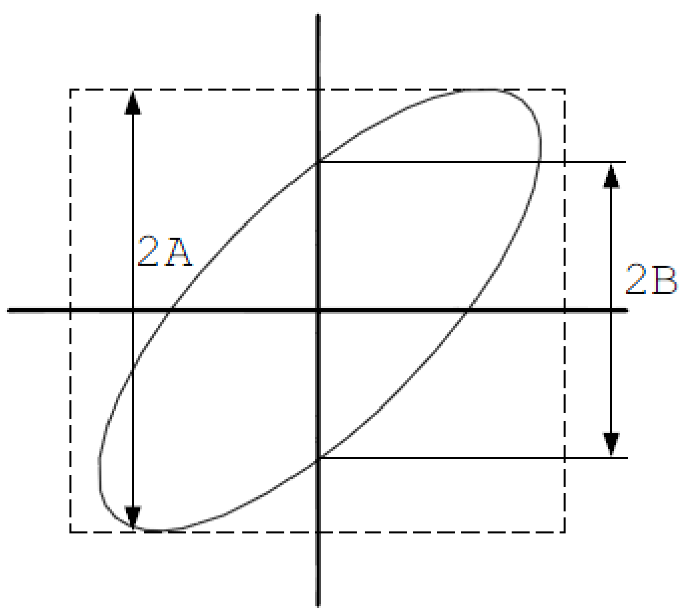


Fig. 2

A3. Measurements and Results:

i. Calculated phase shift:

The phase angle can be calculated using the formula:

$\tan\varphi = X_C/R$, where $X_C = 1/\omega C = 1/2\pi fC$. (f = 5 kHz; R = 20 kΩ; C = 1 nF)

$\tan\varphi = 1/(2\pi 5000{*}10_{-9}{*}20000) = 1.5915$

$\varphi = \tan^{-1}\varphi = 57.858°$

ii. Measured phase shift:

Y-T Format	ΔT = 28µs	T = 200µs	Φ = 50.4°
Lissajous Figure	2B = 5	2A = 6	Φ = 56.443°

iii. Comparison and error:

The calculated values are close to the measured ones. The differences are due to reading errors.

A4. Discussions:

Change the frequency of the input and observe how the shape of the ellipse changes with frequency.

• For what range of frequencies does the ellipse look like a full circle?

The ellipse looks like a full circle for low frequencies (below 1 kHz).

• For what range of frequencies does the ellipse look like a straight line?

The ellipse becomes a straight line for high frequencies (above 10 kHz).

B. Lead and Lag Networks:

B1. Circuit:

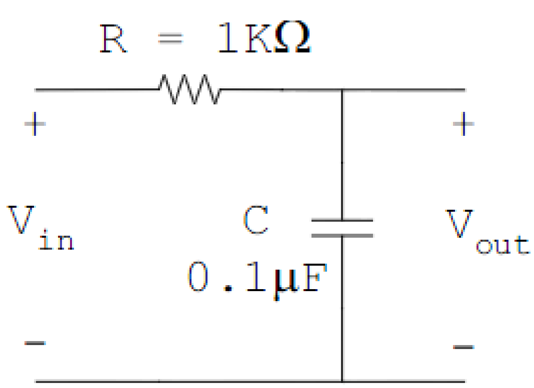


Fig. 3

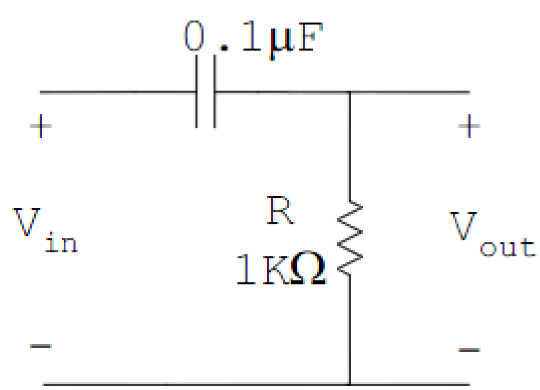


Fig. 4

B2. Detailed experimental procedure:

(a) Sinusoidal Lag Network: Apply a sinusoidal waveform of 100 Hz frequency and 1V peak-to-peak amplitude to the lag network and measure the amplitude of the output voltage on the oscilloscope. Repeat for frequencies of 1 kHz and 10 kHz.

(b) Square Wave Lag Network: Starting with a frequency of 100 Hz on the function generator, apply a square wave input of amplitude 1 V to the lag network shown in Fig. 3. Repeat for square waves with frequencies of 1 kHz and 10 kHz.

(c) Sinusoidal Lead Network: Apply a sinusoidal waveform of 10 kHz frequency and 1V peak-to-peak amplitude to the lead network and measure the amplitude of the output voltage on the oscilloscope. Repeat for frequencies of 1 kHz and 100 Hz.

(d) Square Wave Lead Network: Starting with a frequency of 10 kHz on the function generator, apply a square wave input of amplitude 1 V to the lead network shown in Fig. 4. Repeat for square waves with frequencies of 1 kHz and 100 Hz.

B3. Measurements and Results:

i. Lag Network Calculated:

Frequency	Input Voltage (Vpk-to-pk)	Output Voltage (Vpk-to-pk)
100 Hz	1 V	998.032 mV
1 kHz	1 V	846.733 mV
10 kHz	1 V	157.176 mV

ii. Lag Network Measured:

(a) Sinusoidal Voltage:

Frequency	Input Voltage (Vpk-to-pk)	Output Voltage (Vpk-to-pk)
100 Hz	1 V	1000 mV
1 kHz	1 V	900 mV
10 kHz	1 V	166 mV

(b) Square Wave:

Frequency	Input Voltage (Vpk-to-pk)	Output Voltage (Vpk-to-pk)
100 Hz	1 V	1060 mV
1 kHz	1 V	1040 mV
10 kHz	1 V	316 mV

iii. Lag Network Traces:

(a) Sinusoidal Voltage:

Fig. 5:100 Hz (sine)

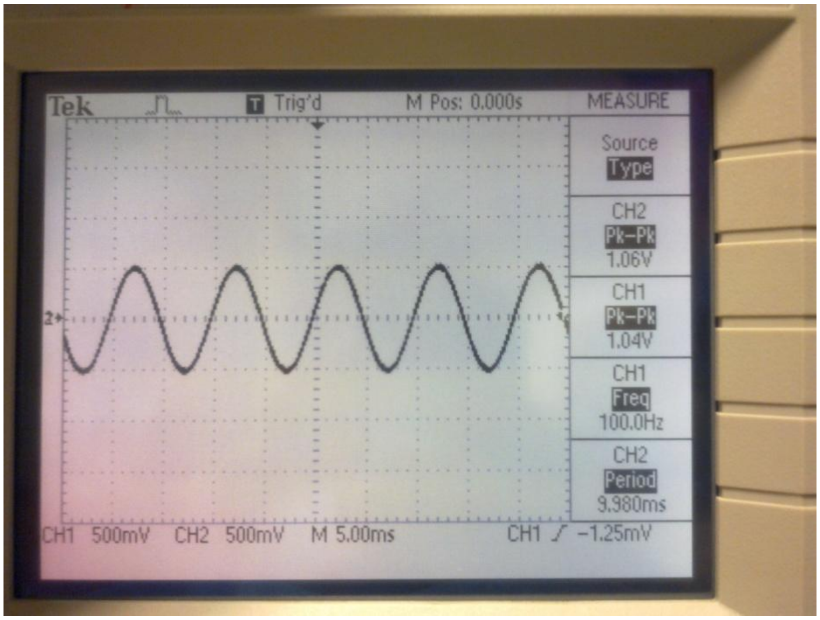


Fig. 6: 1 kHz (sine)

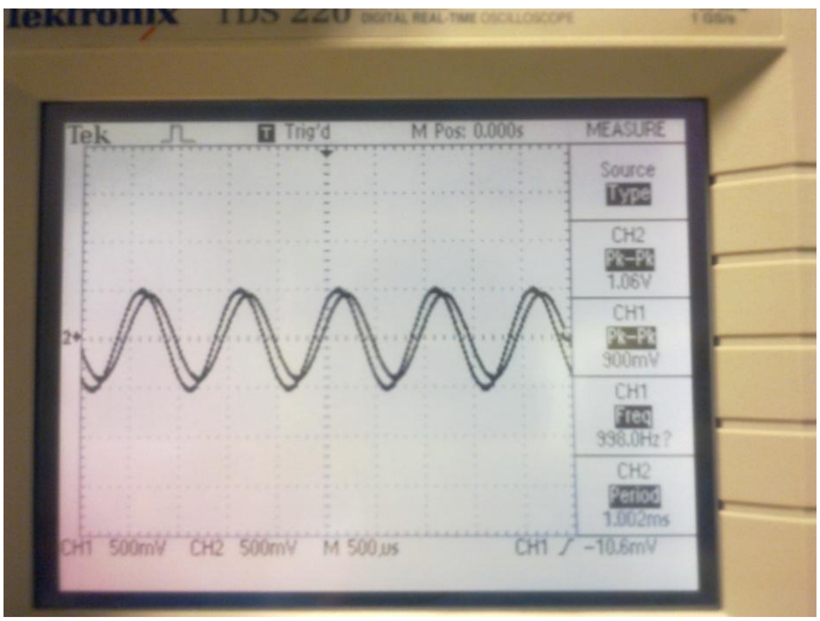
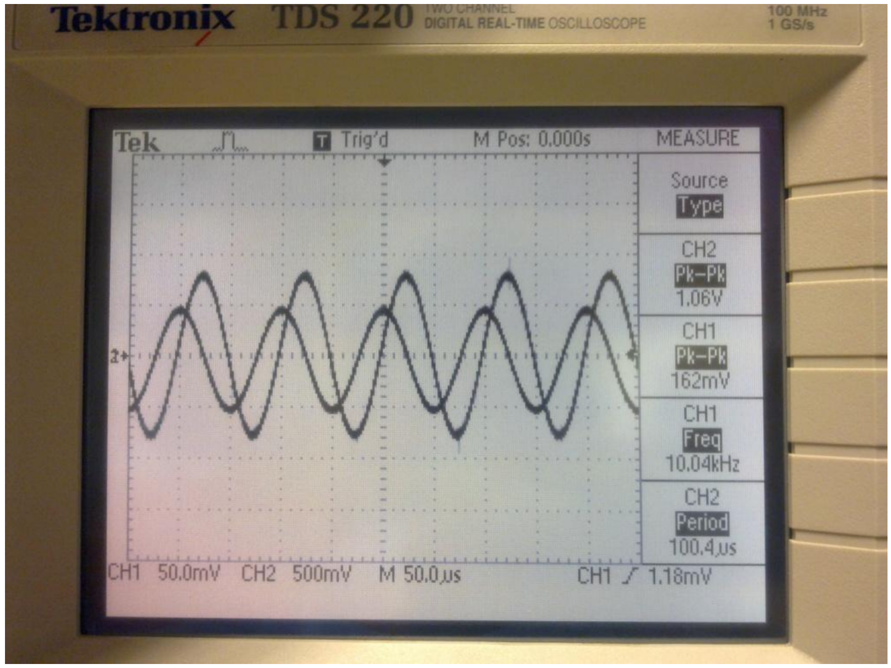
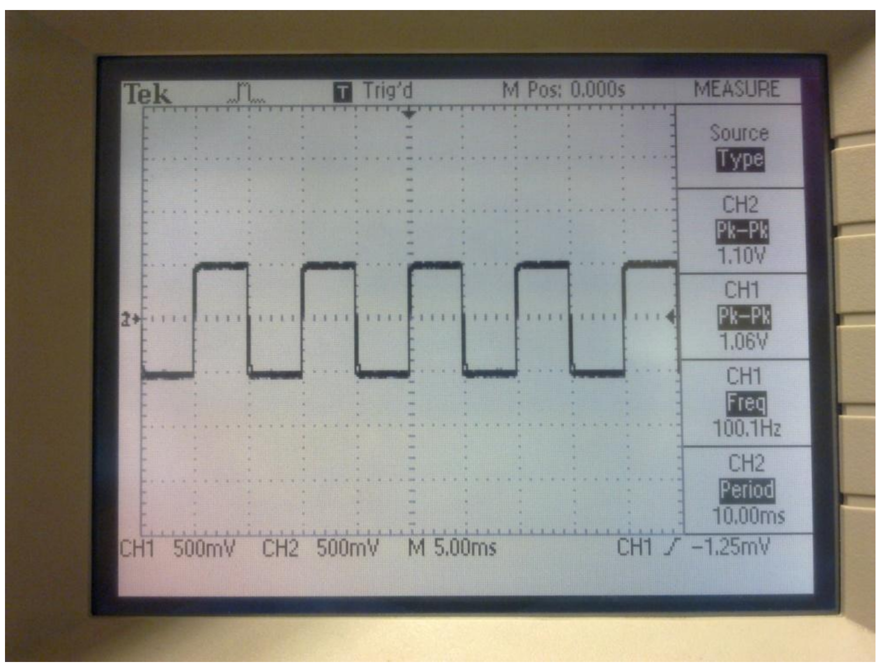


Fig. 7: 10 kHz (sine)



(b) Square Wave Input:

Fig. 8: 100 Hz (square)



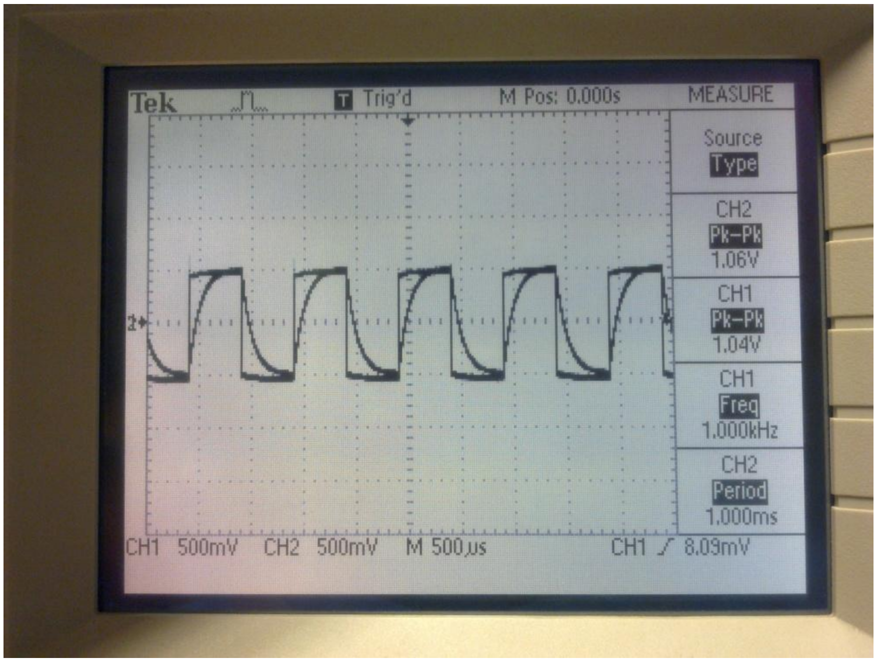


Fig. 9: 1 kHz (square)

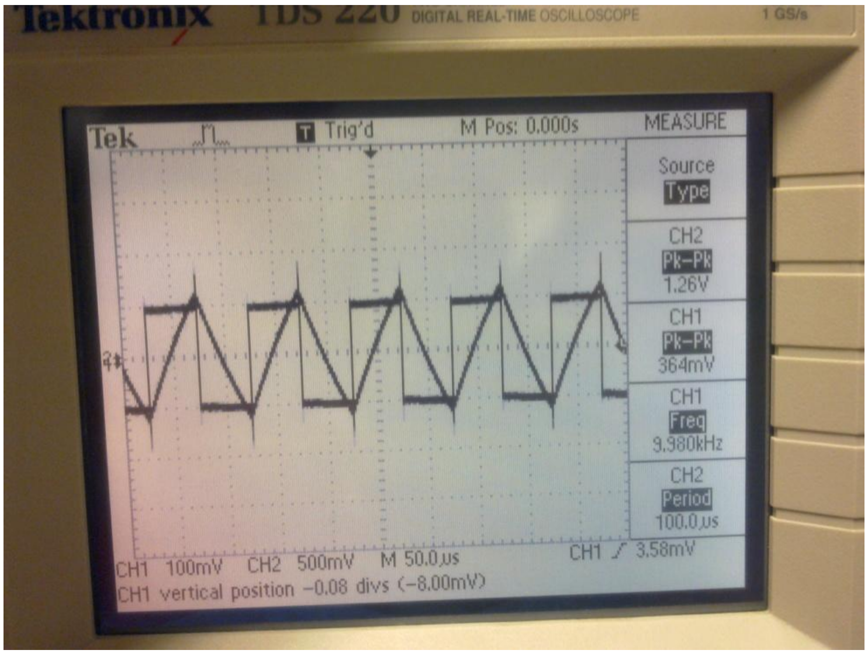


Fig. 10: 10 kHz (square)

i. Lead Network Calculated:

Frequency	Input Voltage (Vpk-to-pk)	Output Voltage (Vpk-to-pk)
100 Hz	1 V	62.7 mV
1 kHz	1 V	532.018 mV
10 kHz	1 V	987.5 mV

ii. Lead Network Measured:

(a) Sinusoidal Voltage:

Frequency	Input Voltage (Vpk-to-pk)	Output Voltage (Vpk-to-pk)
100 Hz	1 V	74 mV
1 kHz	1 V	528 mV
10 kHz	1 V	1020 mV

(b) Square Wave:

Frequency	Input Voltage (Vpk-to-pk)	Output Voltage (Vpk-to-pk)
100 Hz	1 V	1.90 V
1 kHz	1 V	2.00 V
10 kHz	1 V	1.26 V

iii. Lead Network Traces:

(a) Sinusoidal Voltage:

Fig. 11: 100 Hz (sine)

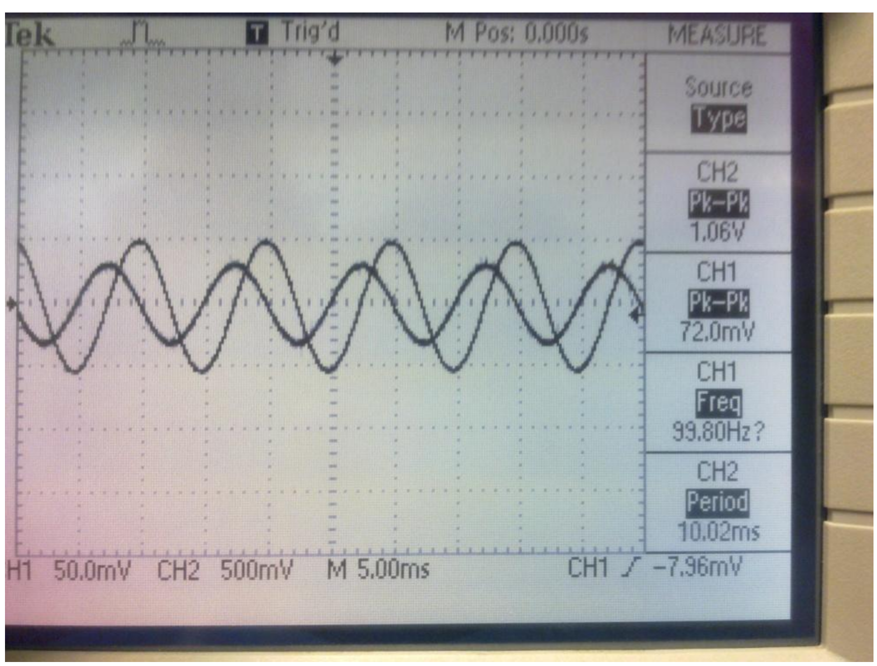


Fig. 12: 1 kHz
(sine)

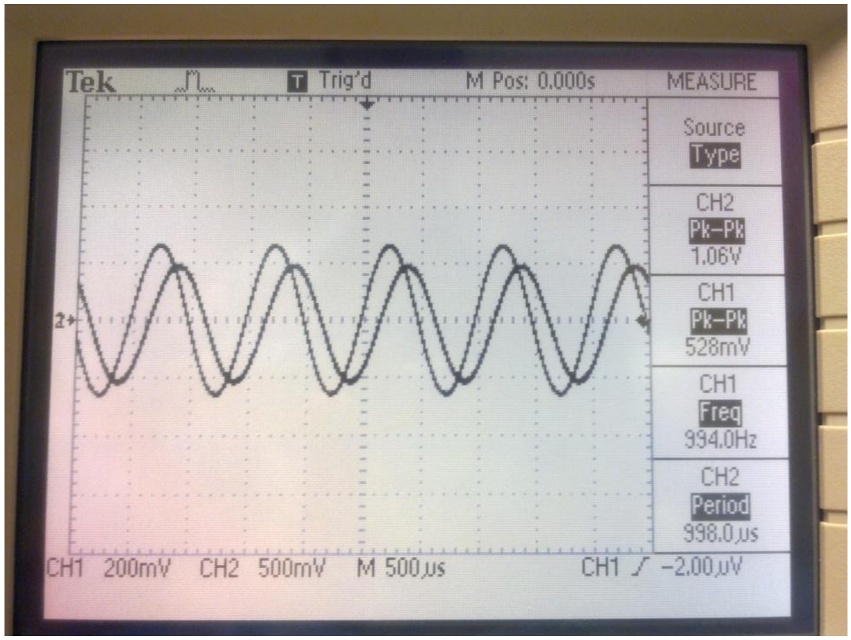
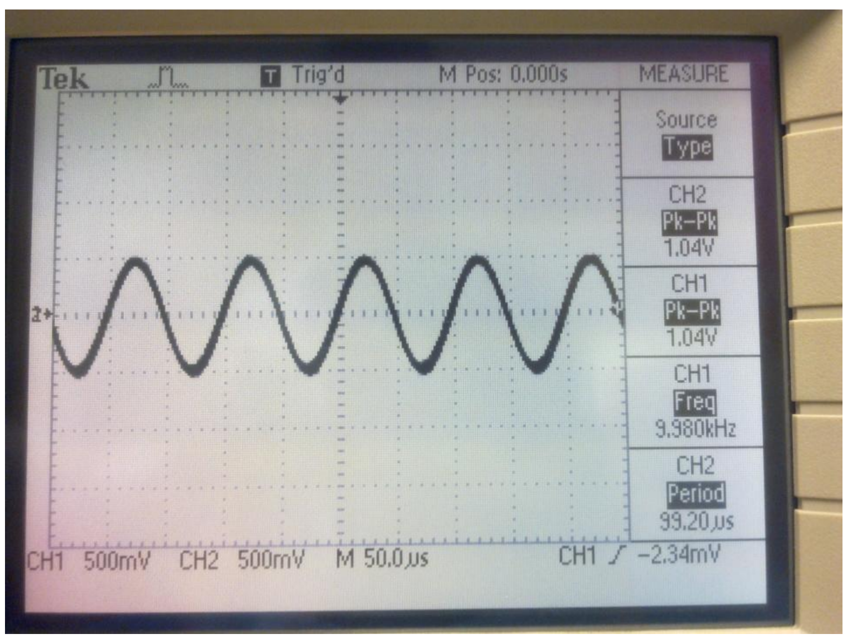


Fig. 13: 10 kHz
(sine)



(b) Square Wave Input:

Fig. 14: 100 Hz (square)

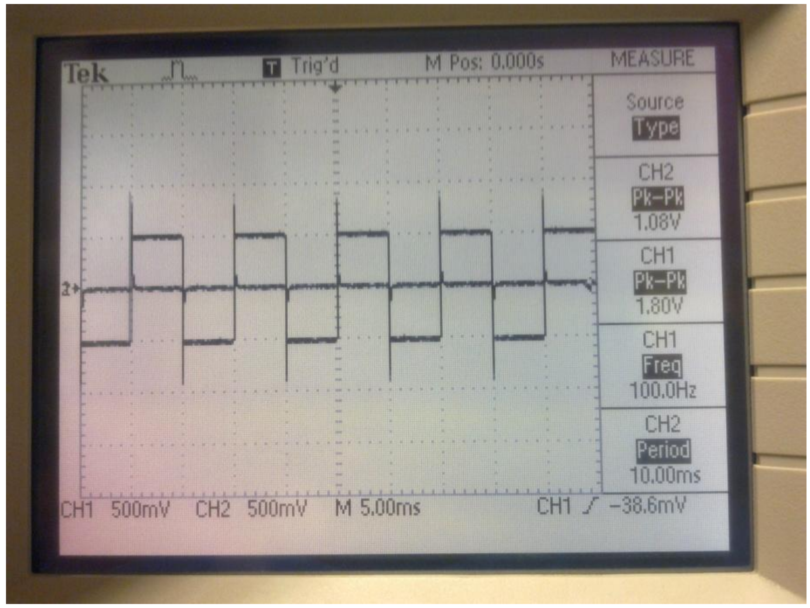


Fig. 15: 1 kHz (square)

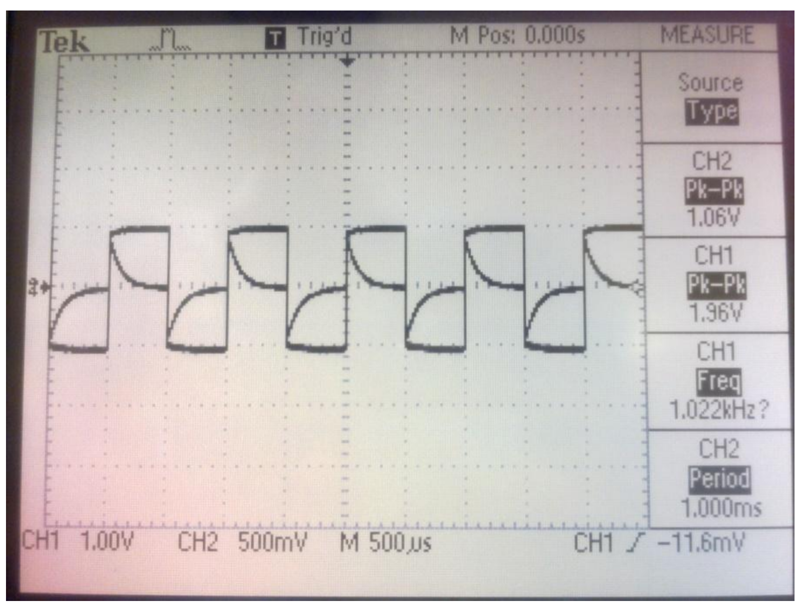
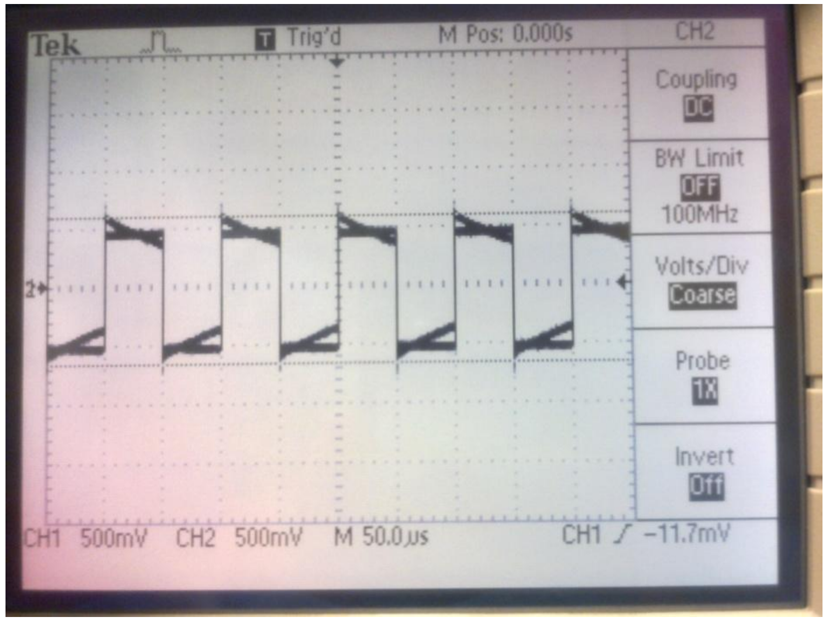


Fig. 16: 10 kHz (square)



vii. Comparison and Error:

The theoretical answers obtained are close to the real and measured ones. The error is due to several reasons including reading errors, equipment errors.

B4. Discussions:

1. Explain the shape of the output waveforms of the lag and lead networks to square wave inputs of various frequencies, with particular reference to the fundamental property of a capacitor not changing its voltage instantaneously.

The output voltage differs for the lag and the lead network. For the lead network, as frequency decreases, the waveform (representing Vout) tends to deviate more from its square shape. For the lag network, as frequency increases, the waveform (representing Vout) tends to deviate more from its square shape. This is due to the fundamental property of a capacitor not changing its voltage instantaneously Vc=Vo(exp(-t/RC)) and V(0-)=V(0+)

2. What should be the relationship between the RC time constant and the frequency of the square wave so that:

(a) The lag network does not appreciably distort the square wave: f>>1/RC

(b) The lag network acts as an integrator: f >> 1/RC

(c) The lead network does not appreciably distort the square wave: f<<1/RC

(d) The lead-network acts as a differentiator: f << 1/RC

*The lag network does not appreciably distort the square wave implying that the lead network is a differentiator, then 1/F >> RC where RC is very small.
*The lead network does not appreciably distort the square wave implying that the lag network is an integrator, then 1/F << RC where RC is very large.

3. What should be the relationship between the RC time constant and the frequency of the sinusoidal input so that:

(a) The lag network does not introduce appreciable attenuation: f<<1/RC
The lag network does not introduce appreciable attenuation, then RC and F are both small.

(b) The lead network does not introduce appreciable attenuation: f>>1/RC
The lead network does not introduce appreciable attenuation, then RC and F are both large.

(c) How do these relationships compare with those for the square wave?
These relationships also hold for the square wave input functions.

(d) What is the relationship between a periodic waveform (such as the square wave) and sinusoids? (Refer to Fourier's Theorem).

The relation is that a periodic waveform is the sum of a DC component and several harmonics on frequencies from ω to nω (n = 1, 2…). Fourier theorem states that any periodic function can be expressed as the sum of sine and cosine terms, each of which has specific amplitude and phase coefficients.

4. The lag and lead networks are also referred to as low-pass and high-pass filters, respectively. Explain what these terms mean and indicate the cutoff frequency in each case.

The lag network represents a low-pass filter, because it passes signals of low frequencies and blocks high frequencies depending on a specific cutoff frequency which is $\omega = 1/RC = 10000$ rad/s. The lead network acts as a high-pass filter that keeps high frequencies and block low ones by the same cutoff frequency as the low-pass filter for same components ($f = \omega/2\pi = 1591.55$ Hz).

The low-pass filter is a filter that passes low frequencies but attenuates frequencies higher than the cutoff frequency (often called the break frequency).
The high-pass filter is a filter that passes high frequencies but attenuates frequencies less than the break frequency.
In case of RC circuit, no matter low-pass or high-pass frequency, $F_b=(1/2\Pi*R*C)$

5. Considering one of the RC elements to be source impedance, and the other to be load impedance, explain the integrating and differentiating action of these networks on the basis of the relationship between source and load impedances in the *s* domain.

*In Differentiator, we consider only low frequencies, so that the capacitor has time to charge up until its voltage almost equals that of the source.

The formula of the differentiating high pass lead filter where C is the source impedance and R is the load impedance is: $H(s)=s/(w_c+s)=s/[s+(1/RC)]$

*In Integrator we consider only high frequencies, so that the capacitor has not enough time to charge up, so the input voltage approximately equals the voltage across the resistor.

The formula of the integrating low pass lag filter where R is the source impedance and C is the load impedance is
$H(s)=wc/(wc+s)=(1/RC)/[s+(1/RC)]$

6. If the input voltage to either network has an average value of V_{DC}, what will be the average value of the voltage across the resistor and the capacitor? What will be the relationship between these three voltage values?

The sum of the average voltages across the capacitor and that across the resistor will be equal to the average value of the input voltage:

VDC= VCDC + VRDC

VI. <u>Mistakes and Problems faced in the lab</u>: We faced a problem with reading the values on the oscilloscope since they were sometimes changing continuously.

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Signature:

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