UNIVERSITY PHYSICS LAB II
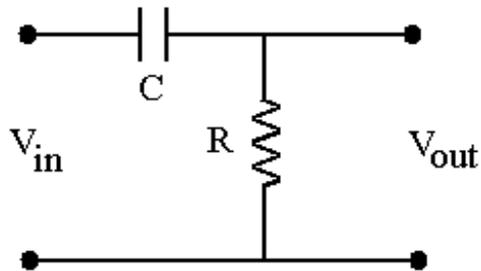
Experiment 4

<u>Attenuation and Phase Shift</u>

Equipment: Function Generator, Dual Trace Oscilloscope

Supplies: 5.6 Kilohm resistor, 0.01 Microfarad capacitor.

The schematic diagram for a high pass RC filter is shown below.

In this experiment, you will study the attenuation (decrease in amplitude) and phase shift of V_{out} relative to V_{in}. These two properties are referred to as the "frequency response" of the RC filter. The filter is called "high pass" because high frequency signals are not attenuated.

A capacitor consists of two conducting plates which are separated by an insulator (dielectric). Equal but opposite charges reside on the two plates as shown below.
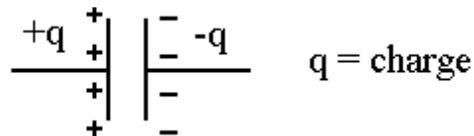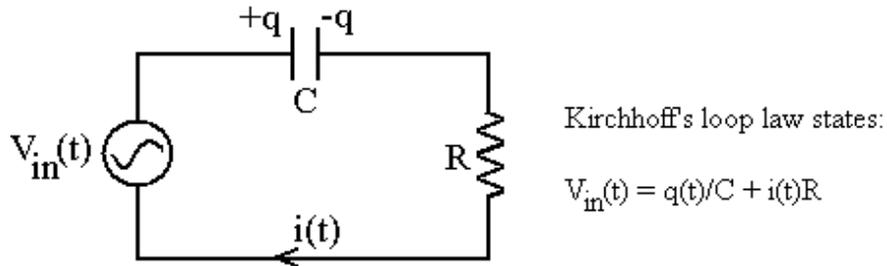

The electric potential of the positively charged plate is higher than the potential of the negatively charged plate by the potential difference.

$$V_c(t) = q(t)/C \qquad\qquad C = \text{capacitance}$$

The unit of capacitance is the farad (1 coulomb/1 farad = 1 volt).

Consider the circuit below which shows the instantaneous charge q(t) and current i(t).

Kirchhoff's loop law states:

$V_{in}(t) = q(t)/C + i(t)R$

Since the capacitor represents an open circuit, the current i(t) is the rate at which the capacitor is charging.

$$i(t) = dq/dt \qquad\qquad\qquad (1)$$

The output voltage is the iR potential drop across the resistor.

$$V_{out} = i(t)R \qquad\qquad\qquad (2)$$

The charge on the capacitor q(t) and current i(t) are out of phase. As the charge builds up on the capacitor the current in the circuit drops. For example, if the current is

$$i(t) = I_p \sin\omega t, \text{ where } \omega = 2\pi f \ \ (f = \text{frequency}) \qquad\qquad (3)$$

then the charge is

$$q(t) = -(I_p/\omega) \cos\omega t = (I_p/\omega) \sin(\omega t - \pi/2) \qquad\qquad (4)$$

Thus the charge lags behind the current by $\pi/2$ radians (90°). The input and output voltages are

$$V_{in} = -(I_p/C\omega)\cos\omega t + I_pR \sin\omega t$$

$$= I_p [R\sin\omega t - (1/C\omega)\cos\omega t]$$

$$V_{out} = I_pR \sin\omega t \qquad\qquad\qquad (5)$$

The input voltage can be expressed compactly as

$$V_{in} = I_pZ \sin(\omega t - \theta) \qquad\qquad\qquad (6)$$

where Z is called the impedance of the series RC circuit and θ is the phase angle (in radians) by which V_{in} lags behind V_{out}.

The impedance of the series RC circuit is

$$Z = \sqrt{R^2 + (1/C\varpi)^2}$$
(7)

and the phase angle is given by

$$\tan \theta = 1/(RC\omega)$$
(8)

The impedance Z is the A.C. analog of resistance.

Procedure - Experiment 5

1.   Measure R with the digital ohmmeter and record.

2..   Begin lab by practicing scrambling and un-scrambling the function generator and oscilloscope. By the end of today's lab it is imperative for you to be comfortable with both these instruments.

3.   Using the scope set the function generator to produce a 10 V(pp) sine wave. This signal will be used for the input in today's experiment. Do not change the amplitude of this signal during the experiment.

4.   Set up the high pass RC filter. Use the function generator to apply a 10 V(pp) sine wave signal to the input. Use the dual trace oscilloscope to look at both V_{in} and V_{out}. Be sure that the two oscilloscope probes have their grounds connected to the function generator ground.

5.   For several frequencies between 20 Hz and 20 kHz (the audio frequency range) measure the peak-to-peak amplitude of V_{out}. Check often to see that V_{in} remains at 10 V(pp) and that VOLTS/DIV dials are in their calibrated positions.
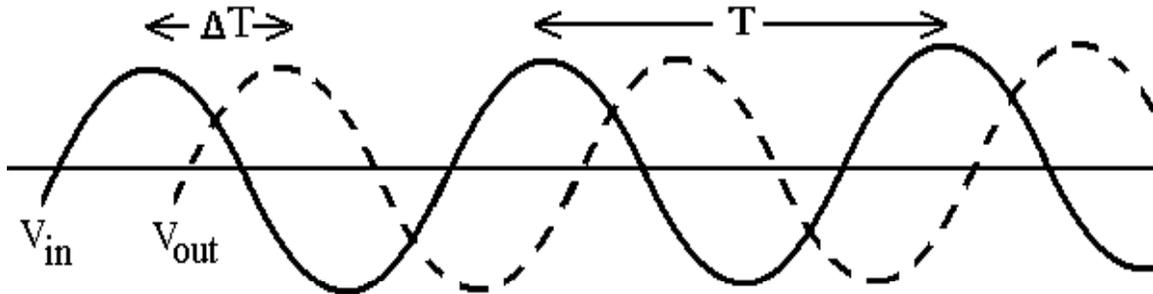
From your <u>measurements</u> determine the ratio

$$\left|\frac{V_{out}}{V_{in}}\right| = \frac{V_{out}(pp)}{V_{in}(pp)}$$

and compute this ratio by using the formula

$$\left|\frac{V_{out}}{V_{in}}\right| = \frac{RC\varpi}{[(RC\varpi)^2 + 1]^{1/2}}$$
(9)

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6.   For each listed frequency between 20 Hz and 20 kHz, measure the phase shift angle θ.
      The diagram below shows V_{in} lagging behind V_{out}.

The phase shift angle in <u>radians</u> is $\theta = (\Delta T/T) \times 2\pi$.

7.   Compute the phase shift angle for each frequency.

Data Sheet - Experiment 4   Name _____

R = _____kΩ   Section # _____

| Frequency	$\omega = 2\pi f$ (rad/sec)	V_{out} (Volts)	Measured V_{out}/V_{in}	Calculated V_{out}/V_{in} (use eq. 9)
20 Hz				
50 Hz				
100 Hz				
200 Hz				
500 Hz				
1 kHz				
2 kHz				
5 kHz				
10 kHz				
20 kHz				

Frequency	ΔT (div)	T (div)	Phase shift θ (rad) $\theta = (\Delta T/T)\times 2\pi$	Phase shift θ (rad) computed from $\tan\theta = 1/(RC\omega)$
20 Hz				
50 Hz				
100 Hz				
200 Hz				
500 Hz				
1 kHz				
2 kHz				
5 kHz				
10 kHz				
20 kHz				

When you finish today's experiment, spend some time practicing with the oscilloscope.

Explain why is acceptable to measure ΔT and T in units of "divisions" instead of "seconds."

A.   Oscilloscope Operation

The front panel of TDS 1002 oscilloscope is given below. It is divided into easy-to-use functional areas.
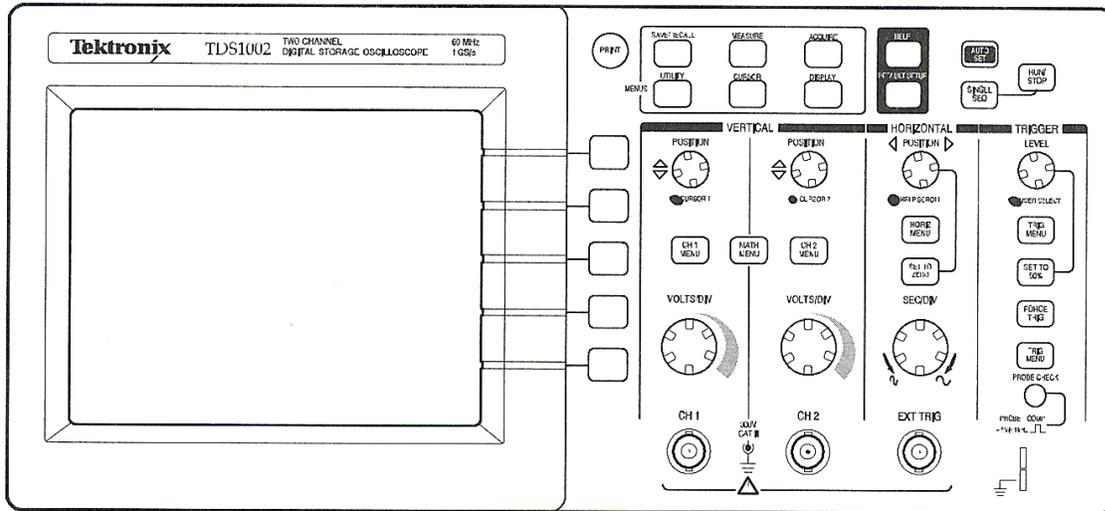
Vertical controls:
Cursor 1 and Cursor 2: Position the waveform vertically.
Ch1 Menu , Ch2 Menu: Display the vertical menu selections and toggles the display of the channel waveform on/off.
Math Menu: Displays the waveform math operations menu.
Volts/Div: Selects calibrated scale factors.
Horizontal controls:
Position: Adjusts the horizontal position of the waveform.
Horiz. menu: Displays the Horizontal menu.
Set to zero: Sets the horizontal position to zero.
Sec/Div: Selects the horizontal time/div (scale factor) for the window time base.
Trigger controls: Used to set up the trigger level.
Menu and Control buttons:
Save/Recall: Displays the Save/Recall menu
Measure: Displays the automated measurements menu
Acquire: Displays the acquire menu
Cursor: Displays the cursor menu
Utility: Displays the utility menu
Auto Set: Automatically sets the oscilloscope controls to produce a usable display of the input signal.
 This is your "panic" button. Punch it in anytime something goes wrong and you do not know why…
Default set up: Recalls the factory set up.
Single Seq: Acquires a single waveform and then stops.
Run/Stop: Continuously acquires waveforms.
Print: Starts print operations.

The BNC connectors labeled Ch1 and Ch2 are two inputs. Each input is an amplifier which takes the input signal and uses it to drive the electron beam up and down. To use channel 1 only, punch in the button Ch 1; similarly for channel 2. Because there are two input channels, the TDS 1002 is called a dual trace oscilloscope. However, there is only one electron beam, which is shared by the two channels.

C.   The Function Generator

The function generator produces square waves, triangle waves, and sine waves shown below:
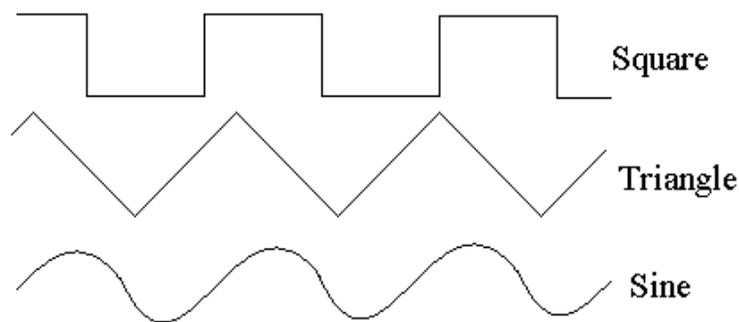
In this Lab you will be using BK PRECISION Model 4017A function generator. The front panel of the generator is given in the next page.

**To operate the generator**:

Turn on the **Power** switch.
Select the waveform of the generated signal by pushing the corresponding **Function** switch.
Push **Range** Selector switch to select the frequency range at your desire. Adjust the frequency of the signal by turning the **Coarse/Fine Frequency** Controls.
The amplitude of the output signal is controlled continuously with operating the **Output Level** Control (use it to generated waveforms with amplitudes from 1 V to 10 V). If the **-20 dB Switch** is also engaged, the output amplitude is reduced by a factor of –20dB (use it to generated waveforms with amplitudes from 100 mV to 1 V)
The **DC OFFSET control** may be used to offset the waveform above or below ground (0 volts) by a D.C. voltage in the range ±10 volts.

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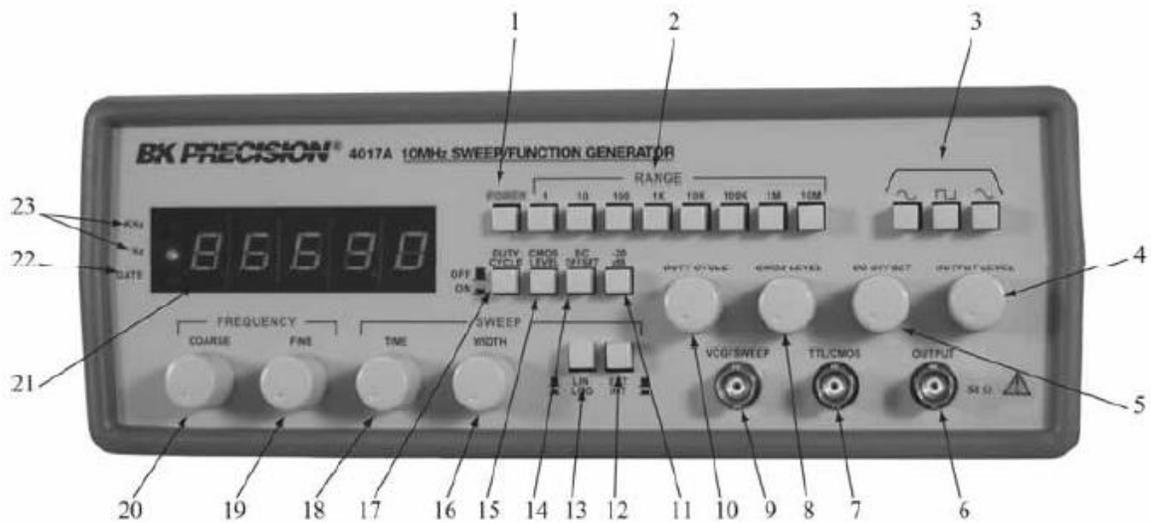
1.   **POWER On/OFF Switch**.
2.   **RANGE Switch**. Seven ranges from 1 Hz to 10MHz
3.   **FUNCTION Switch**. Selects sine, square, or triangle waveforms.
4.   **OUTPUT LEVEL Control**: up to ±20 Vpp (open circuit) or ±10 V pp into 50 Ω.
5.   **DC OFFSET Control**: up to ±10 Vpp (open circuit) or ±5 V pp into 50 Ω.
6.   **OUTPUT Jack** – outputs the generated waveform.
7.   **TTL/CMOS Jack**. TTL or CMOS square wave, selected by switch (15), is output at this jack.
8.   **CMOS LEVEL Control**.
9.   **VCG/SWEEP Jack**.
10.   **DUTY CYCLE Control**.
11.   **-20 dB Switch**. When engaged, the signal at the OUTPUT jack is attenuated by -20dB.
12.   **SWEEP INT/EXT Switch.**
13.   **SWEEP LIN/LOG Switch**.
14.   **DC OFFSET Switch**. When engaged, enables operation of the DC OFFSET control (5).
15.   **CMOS LEVEL Switch**.
16.   **SWEEP WIDTH Control**.
17.   **DUTY CYCLE Switch**.
18.   **SWEEP TIME Control.**
19.   **FINE FREQUENCY Control**.
20.   **COARSE FREQUENCY Control**.
21.   **COUNTER DISPLAY**. Displays frequency of internally generated waveform.
22.   **GATE LED**. Indicates when the frequency counter display is updated.
23.   **Hz and KHz LED**. Indicates whether the counter is reading in Hz or kHz

<u>The Function Generator</u>

    1.   Set the function generator for a 1 volt p-p, 1 kHz signal.

    2.   Connect the function generator cable to the channel 1 oscilloscope probe.

    3.   With the channel 1 input on AC, measure the peak-to-peak voltage of the 1 kHz signal (nominally 1 volt). Note the following: (a) setting of the Volts/Div control, and (b) number of divisions (centimeters) peak-to-peak.

    4.   Measure the frequency of the 1 kHz signal. Note the following: (a) setting of the Sec/Div dial, and (b) number of divisions (centimeters) between successive peaks.

    5.   Switch channel 1 to GND (be sure that the Triggering Mode is Auto) to establish the ground level on the scope screen. Use the Position control to put the ground level in the center of the screen.

    6.   Switch channel 1 to DC and determine the maximum D.C. offset voltages (both positive and negative) that can be added to the 1 kHz signal voltage.

D.   <u>Oscilloscope Practice</u>

Your lab partner should adjust every knob on the oscilloscope and function generator. Then you should try to obtain this signal .

$$T = 1 \text{ msec}$$
$$V_{pp} = 5 \text{ volts}$$
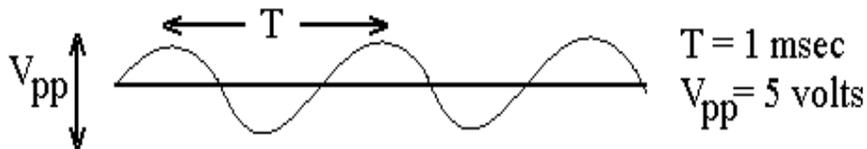
Now it is your turn. Adjust all the knobs and ask your partner to find these two signals:

Signal 1

$$T = 500 \text{ usec}$$
$$V_{pp} = 8 \text{ volts}$$
Ground

Signal 2

Ground
$$T = 20 \text{ msec}$$
$$V_{pp} = 10 \quad \text{volts}$$