University of Jordan
School of Engineering
Electrical Engineering Department

EE 219
Electrical Circuits Lab

EXPERIMENT 9
TRANSFER FUNCTION
OF TWO-PORT NETWORKS

Prepared by: Dr. Mohammed Hawa

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TRANSFER FUNCTION
OF TWO-PORT NETWORKS

OBJECTIVE

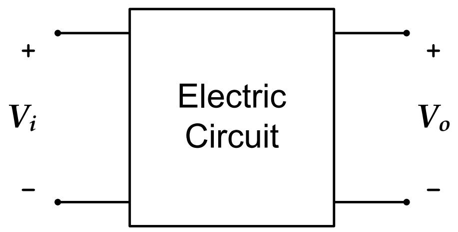
This experiment investigates the transfer function of several two-port networks including: low-pass filter (LPF), high-pass filter (HPF) and bandpass filter (BPF).

DISCUSSION

Transfer function

The transfer function $\boldsymbol{H}(f)$ of a two-port network (circuit), such as the one shown below, represents the ratio of the output voltage to the input voltage as the frequency of the input voltage is varied. In other words,

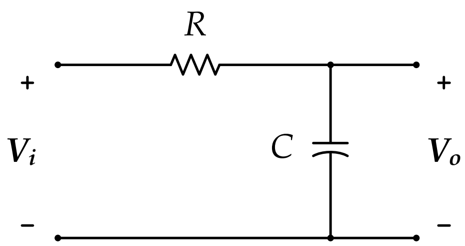
$$\boldsymbol{H}(f) = \frac{\boldsymbol{V_o}(f)}{\boldsymbol{V_i}(f)}$$



Since the input and output voltages in AC circuits are complex quantities, $\boldsymbol{H}(f)$ is also a complex quantity with magnitude $|\boldsymbol{H}(f)|$ and phase $\measuredangle\boldsymbol{H}(f)$. The transfer function is useful to describe how the electric circuit behaves under different input frequencies. An important example where this useful is filters.

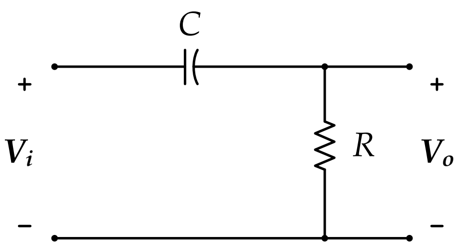
Low-pass Filter (LPF)

A LPF is a two-port electric circuit that only passes low frequency AC signals from the input to the output, while blocking high frequency AC signals from passing to the output. The simplest LPF that we can build is the first-order RC circuit shown below.



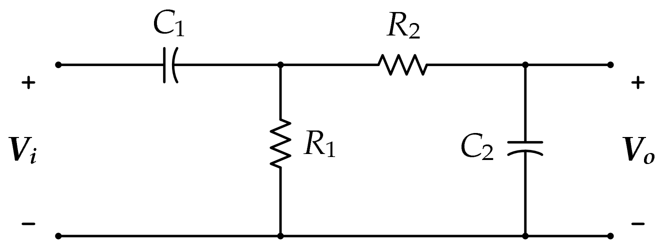
At low frequency, the capacitor approaches an open circuit, preventing current from passing thought the resistor, hence causing the output voltage to be the same as the input voltage; while at high frequency, the capacitor approaches a short circuit causing the output voltage to be zero, irrespective of the input voltage.

High-pass Filter (HPF)
A HPF is a two-port electric circuit that only passes high frequency AC signals from the input to the output, while blocking low frequency AC signals. The simplest HPF that we can build is the RC circuit shown below, which is different than the LPF design above.



At low frequency, the capacitor approaches an open circuit, preventing current from passing thought the resistor, causing the output voltage to be zero; while at high frequency, the capacitor approaches a short circuit between the input and output, causing the output voltage to be the same as the input voltage.

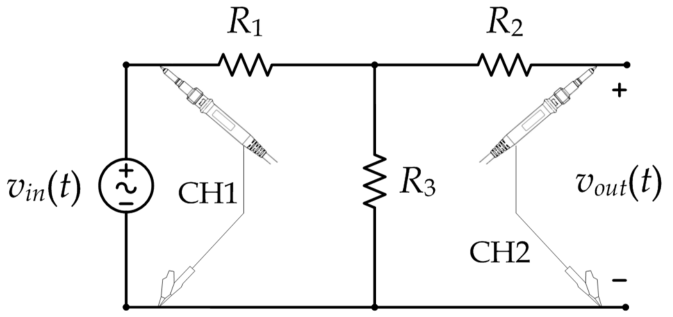
Band-pass Filter (BPF)
A BPF is a two-port electric circuit that blocks both low frequencies and high frequencies, but passes frequencies in between. There are many different designs for BPFs, including the use of resonant circuits. The one shown below is a two-stage filter consisting of a LPF stage that follows a HPF stage.



It is worth mentioning that the circuits presented above are a small subset of many possible designs for filters. For example, we can also build LPFs, HPFs, and BPFs using inductors instead of (or in combination with) capacitors. We can also build higher order filters (i.e., sharper filters) by increasing the number of components (resistors and capacitors) in the circuit. In addition, active filters can be designed to provide amplification (i.e., gain higher than 1.0) by adding transistors or Op-Amps (operational amplifiers) to the circuit. These more advanced designs are beyond the scope of this lab, but it must be remembered that whenever possible, designers prefer to use capacitors over inductors in real-life circuits, because inductors are usually bulky, more expensive, can cause more interference due to their magnetic field, and their practical model does not fit perfectly with the ideal inductor model.

PROCEDURE A – RESISTIVE TWO-PORT NETWORK

1. Construct the circuit shown below. Assume that R_1 = 1000 Ω, R_2 = 510 Ω, and R_3 = 1500 Ω.



2. Set the function generator to produce a sinusoidal waveform (AC) with frequency of 430 Hz, and *peak voltage* of $V_p = 3$ V.

CAUTION: Some older function generators have a defect and produce an AC signal with a slight DC shift. Hence, if you do not see a symmetric sinusoidal signal above and below zero volts, adjust the DC offset knob slightly to force a zero DC offset in the function generator output.

3. Use theoretical analysis to determine the voltages $|\boldsymbol{V_{in}}|$ and $|\boldsymbol{V_{out}}|$ in the circuit at the different frequencies in Table 1. Record the answers in Table 1.

4. What is the theoretical equation for the transfer function $|\boldsymbol{H}(\boldsymbol{f})|$ in the above circuit?

. . . .

5. Is the above equation dependent on frequency or not?

. . . .

6. Use the oscilloscope to measure the peak values of the voltages $\boldsymbol{V_{in}}$ and $\boldsymbol{V_{out}}$. Record the measurements in Table 1?

CAUTION: Whenever you change the frequency of the function generator, verify the period of the signal from the oscilloscope to get accurate readings. Also re-check the peak-to-peak voltage as the function generator might change the amplitude when you change the frequency.

7. Using theoretical and measured values, evaluate the transfer function $|\boldsymbol{H}(\boldsymbol{f})|$ for this two-port network in the last column of Table 1.

8. Using the measured values in Table 1, plot (**by hand** using the graph paper attached at the end of the report) the transfer function $|\boldsymbol{H}(\boldsymbol{f})|$ versus source frequency.

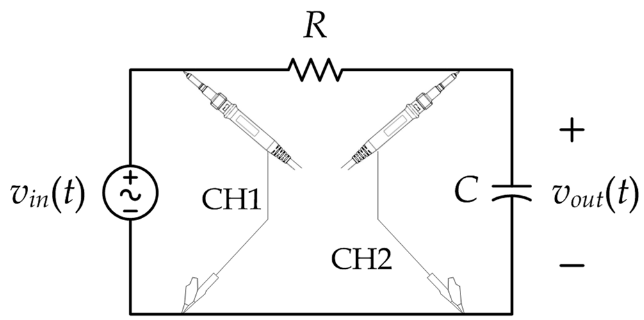
9. For the above plot, state your conclusions under the plot?

Table 1

AC Source Frequency (kHz)	$\lvert V_{in} \rvert$ (peak) (V)		$\lvert V_{out} \rvert$ (peak) (V)		$\lvert H(f) \rvert = \lvert V_{out} \rvert / \lvert V_{in} \rvert$	
	Theory	Meas.	Theory	Meas.	Theory	Meas.
0.43						
2.9						
4.3						
17						
57						
96						
120						
140						
1900						

PROCEDURE B – LOW-PASS FILTER TWO-PORT NETWORK

1. Construct the circuit shown below. Assume that R = 1.5 kΩ and C = 1 nF.



2. Set the function generator to produce a sinusoidal waveform (AC) with frequency of 430 Hz, and *peak voltage* of $V_p = 3$ V.

CAUTION: Some older function generators have a defect and produce an AC signal with a slight DC shift. Hence, if you do not see a symmetric sinusoidal signal above and below zero volts, adjust the DC offset knob slightly to force a zero DC offset in the function generator output.

3. Use theoretical analysis to determine the voltages $\lvert \boldsymbol{V_{in}} \rvert$ and $\lvert \boldsymbol{V_{out}} \rvert$ in the circuit at the different frequencies in Table 2. Record the answers in Table 2.

4. What is the theoretical equation for the transfer function $\lvert \boldsymbol{H(f)} \rvert$ in the above circuit?

. . . .

5. Is the above equation dependent on frequency or not?

. . . .

6. What is the equation for the cut-off frequency f_c of the first order RC circuit shown above?

. . . .

7. Use the above equation to find the frequency f_c, at which the output voltage is approximately 0.707 times the maximum possible output voltage (i.e., the half-power point). Record this value below. **Then** use the oscilloscope to determine this cutoff frequency experimentally by observing the frequency at which the output voltage is approximately 0.707 times the maximum. Record this *experimental* frequency in Table 2.

. . . .

8. Use the oscilloscope to measure the peak values of the voltages $\boldsymbol{V_{in}}$ and $\boldsymbol{V_{out}}$. Record the measurements in Table 2?

CAUTION: Whenever you change the frequency of the function generator, verify the period of the signal from the oscilloscope to get accurate readings. Also re-check the peak-to-peak voltage as the function generator might change the amplitude when you change the frequency.

Table 2

AC Source Frequency (kHz)	$\lvert\boldsymbol{V_{in}}\rvert$ **(peak) (V)**		$\lvert\boldsymbol{V_{out}}\rvert$ **(peak) (V)**		$\lvert\boldsymbol{H(f)}\rvert = \lvert\boldsymbol{V_{out}}\rvert/\lvert\boldsymbol{V_{in}}\rvert$	
	Theory	**Meas.**	**Theory**	**Meas.**	**Theory**	**Meas.**
0.43						
4.3						
57						
76						
96						
120						
130						
140						
1900						
$f_c =$ ______						

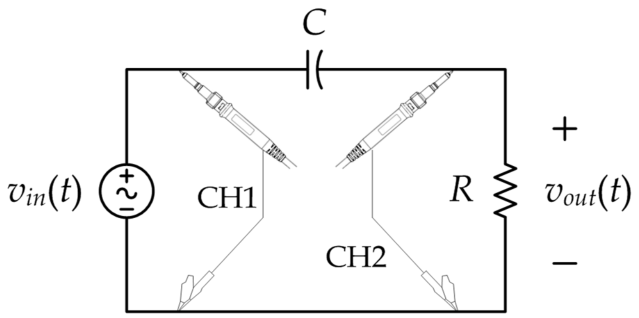
9. Using theoretical and measured values, evaluate the transfer function $\lvert\boldsymbol{H(f)}\rvert$ for this two-port network in the last column of Table 2.

10. Using the measured values in Table 2, plot (**by hand** using the graph paper attached at the end of the report) the transfer function $\lvert\boldsymbol{H(f)}\rvert$ versus source frequency.

11. For the above plot, state your conclusions under the plot? Also identify the cut-off frequency in the plot.

PROCEDURE C – HIGH-PASS FILTER TWO-PORT NETWORK

1. Construct the circuit shown below. Assume that R = 220 Ω and C = 0.1 μF.



2. Set the function generator to produce a sinusoidal waveform (AC) with frequency of 430 Hz, and *peak voltage* of $V_p = 3$ V.

CAUTION: Some older function generators have a defect and produce an AC signal with a slight DC shift. Hence, if you do not see a symmetric sinusoidal signal above and below zero volts, adjust the DC offset knob slightly to force a zero DC offset in the function generator output.

3. Use theoretical analysis to determine the voltages $|\boldsymbol{V_{in}}|$ and $|\boldsymbol{V_{out}}|$ in the circuit at the different frequencies in Table 3. Record the answers in Table 3.

4. What is the theoretical equation for the transfer function $|\boldsymbol{H}(\boldsymbol{f})|$ in the above circuit?

. . . .

5. Is the above equation dependent on frequency or not?

. . . .

6. What is the equation for the cut-off frequency f_c of the first order RC circuit shown above?

. . . .

7. Use the above equation to find the frequency f_c, at which the output voltage is approximately 0.707 times the maximum possible output voltage (i.e., the half-power point). Record this value below. **Then** use the oscilloscope to determine this cutoff frequency experimentally by observing the frequency at which the output voltage is approximately 0.707 times the maximum. Record this *experimental* frequency in Table 3.

. . . .

8. Use the oscilloscope to measure the peak values of the voltages $\boldsymbol{V_{in}}$ and $\boldsymbol{V_{out}}$. Record the measurements in Table 3?

CAUTION: Whenever you change the frequency of the function generator, verify the period of the signal from the oscilloscope to get accurate readings. Also re-check the peak-to-peak voltage as the function generator might change the amplitude when you change the frequency.

Table 3

AC Source Frequency (kHz)	$\lvert V_{in}\rvert$ (peak) (V)		$\lvert V_{out}\rvert$ (peak) (V)		$\lvert H(f)\rvert = \lvert V_{out}\rvert / \lvert V_{in}\rvert$	
	Theory	**Meas.**	**Theory**	**Meas.**	**Theory**	**Meas.**
0.43						
2.9						
4.3						
5.8						
17						
37						
57						
560						
1900						
f_c = ______						

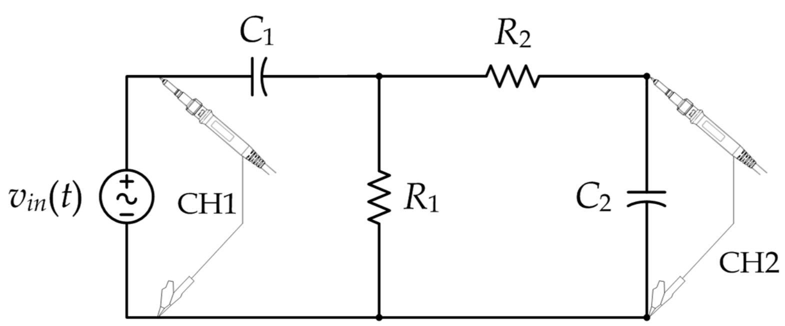
9. Using theoretical and measured values, evaluate the transfer function $\lvert\boldsymbol{H(f)}\rvert$ for this two-port network in the last column of Table 3.

10. Using the measured values in Table 3, plot (**by hand** using the graph paper attached at the end of the report) the transfer function $\lvert\boldsymbol{H(f)}\rvert$ versus source frequency.

11. For the above plot, state your conclusions under the plot? Also identify the cut-off frequency in the plot.

<u>PROCEDURE D – BANDPASS FILTER TWO-PORT NETWORK</u>

1. Construct the circuit shown below. Assume that R_1 = 220 Ω, C_1 = 0.1 µF, R_2 = 1.5 kΩ and C_2 = 1 nF.



2. Set the function generator to produce a sinusoidal waveform (AC) with frequency of 430 Hz, and *peak voltage* of $V_p = 3$ V.

CAUTION: Some older function generators have a defect and produce an AC signal with a slight DC shift. Hence, if you do not see a symmetric sinusoidal signal above and below zero volts, adjust the DC offset knob slightly to force a zero DC offset in the function generator output.

3. Use theoretical analysis to determine the voltages $|\boldsymbol{V_{in}}|$ and $|\boldsymbol{V_{out}}|$ in the circuit at the different frequencies in Table 4. Record the answers in Table 4.

4. What is the theoretical equation for the transfer function $|\boldsymbol{H}(\boldsymbol{f})|$ in the above circuit?

. . . .

5. Is the above equation dependent on frequency or not?

. . . .

6. What are the equations for the two cut-off frequencies of the above ladder circuit?

. . . .

7. Use the above equations to find the frequencies, at which the output voltage is approximately 0.707 times the maximum possible output voltage (i.e., the half-power points). Record these values below. **Then** use the oscilloscope to determine such cutoff frequencies experimentally by observing the frequency at which the output voltage is approximately 0.707 times the maximum. Record these *experimental* frequencies in Table 4.

. . . .

8. Use the oscilloscope to measure the peak values of the voltages $\boldsymbol{V_{in}}$ and $\boldsymbol{V_{out}}$. Record the measurements in Table 4?

CAUTION: Whenever you change the frequency of the function generator, verify the period of the signal from the oscilloscope to get accurate readings. Also re-check the peak-to-peak voltage as the function generator might change the amplitude when you change the frequency.

9. Using theoretical and measured values, evaluate the transfer function $|\boldsymbol{H}(\boldsymbol{f})|$ for this two-port network in the last column of Table 4.

10. Using the measured values in Table 4, plot (**by hand** using the graph paper attached at the end of the report) the transfer function $|\boldsymbol{H}(\boldsymbol{f})|$ versus source frequency.

11. For the above plot, state your conclusions under the plot? Also identify the two cut-off frequencies in the plot.

Table 4

AC Source Frequency (kHz)	$\lvert V_{in} \rvert$ (peak) (V)		$\lvert V_{out} \rvert$ (peak) (V)		$\lvert H(f) \rvert = \lvert V_{out} \rvert / \lvert V_{in} \rvert$	
	Theory	Meas.	Theory	Meas.	Theory	Meas.
0.43						
4.3						
5.8						
37						
57						
76						
120						
130						
1900						
f_{c1} = ______						
f_{c2} = ______						

**** End ****