IERG1810 - Experiment 2
AC Circuit Analysis

Objectives

- To study the characteristics of some passive components in Alternating Current (AC) circuits.
- To use vector diagram to represent impedance.
- To use log paper and bold plot to represent transfer function and phase shift.
- To study the resonance characteristics in RLC (resistor, inductor and capacitor) circuits.
- To measure inductance and capacitance with LC meter.
- To study Ohm's law, Kirchhoff's circuit laws and Thévenin's equivalent circuits in AC circuits.
- To study diode's characteristics, half bridge and full bridge rectifier circuits.

Equipment

- Oscilloscope
- DC Power Supply
- Digital Multi-meter (DMM)
- Signal Generator
- Prototype Breadboard
- LC Meter

Components

- Resistor
- Capacitor
- Diode
- Inductor

Introduction

In electronics, the characteristics of components can be represented with resistance (R-resistor) and reactance (L-inductor and C-capacitor), they are out of phase (90 degree or orthogonal) and can be represented with phasor diagram easily.

- https://www.powermetrix.com/2016/03/vectors/
- Only resistance consumes energy.

In Experiment 1, we have learnt the use of some equipment in Direct Current (DC) circuits. Current and Voltage are in-phase in DC circuits.

Voltage = Current * Resistance

Power = Voltage * Current.

Before doing experiments with *Alternating Current (AC) circuits*, we will study differentiation and integration effects of a step pulse (transient) signal applied to the reactance component in experiment-2.1 to experiment-2.3. The voltage and current are changed and against time.

In AC circuits, the signal repeats in form of a sinusoidal wave. Reactance components' (capacitor and inductor) characteristics (impedance = resistance and reactance on two orthogonal dimensions) are related to the frequency of the signal. Current and Voltage in AC circuits are not in-phase anymore. Current leads Voltage at Capacitor; Voltage leads Current at Inductor. The maximum phase difference between reactive components (L or C) is 90 degrees in ideal case. We will study a special case; serial resonance circuit that represent with vector diagram.

- https://circuitglobe.com/what-is-rlc-series-circuit.html (read this page and know how to draw phasor diagram)

AC signals can pass through a capacitor easily (low impedance) but DC cannot. We use this characteristic to remove (block) DC signal by having a capacitor in series with the circuit. Or remove (by pass) the AC signal via a parallel capacitor, which is called as *decoupling capacitor*.

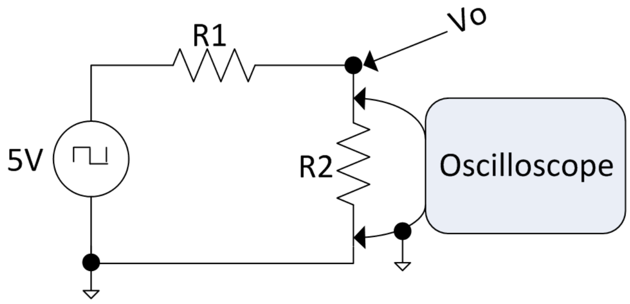
P and N type semi-conductors join together to form a P-N junction. Current can pass through the junction in one direction (forward) only, diodes are the products with single P-N junction semi-conductor. We will learn the characteristics of a diode and make half wave and full wave rectifiers, which are basic circuits to convert an AC signal to DC signal. A parallel capacitor helps to remove the ripple (by pass AC signal and storage energy) of this rectifier circuit.

In Experiment-1, we have learnt the Open-short method, it is not good to measure the extremely low internal resistance of a DC source. Battery is an ultra-low internal resistance example, then we can use a 'battery internal resistance meter' to measure it. ‘battery internal resistance meter’ uses an AC signal (block DC current) to measure the DC power source.

To measure an AC source’s impedance, we cannot use the same method. We have to use Thevenin’s equivalent circuits or maximum power transfer method to measure the internal resistance of AC source.

In Experiment-1, we have learnt that the oscilloscope and the signal generator are both grounded equipment. A transformers (1:1) is use to isolate oscilloscope’s channels and signal generator in experiment-2.12 to solve the grounding problem.

Experiment 2.1: Transient signal to RR circuit



R1 = 1KΩ

R2 = 1KΩ

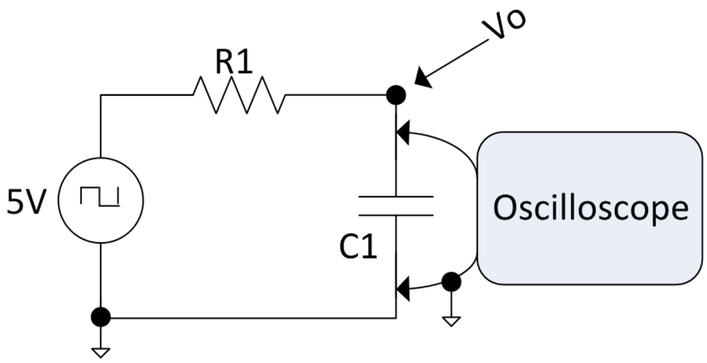
The circuit above is a simple potential divider and built with two resistors, where the input signal is a square wave (transient, step change).

Note: This circuit uses two resistors, no reactance device is used.

Procedures

1. Set the Signal Generator output to 5Vp-p (peak-to-peak), 2.5V DC offset, Square wave with 1KHz. It must be a 50% periodic pulse swinging between 0V and 5V, check the waveform of the Signal Generator with an oscilloscope channel.
2. Build the circuit on the breadboard.
3. Measure the voltage V_o across R2 with an oscilloscope channel. Record and compare the waveforms of signal 5.0V source and Vo. 2.5V
4. Repeat steps 2 to 4 with R1 = 10 KΩ. (10 times of the previous value).
5. Explain your observations. What theories (see Experiment-1) can be applied to explain your results?

Experiment 2.2: Transient signal to RC circuit



R1 = 1KΩ

C1 = 100nF

Now, R2 is replaced with a capacitor C1 (reactance device), you can see the differentiation and integration effects, via charging and discharging of C1. Its results is related to the natural value e (2.71828) and time.

Discharging equation of RC circuit $\mathrm{Vo} = \mathrm{Vs} * e^{\frac{-t}{RC}}$

Charging equation of RC circuit $\mathrm{Vo} = \mathrm{Vs} * (1 - e^{\frac{-t}{RC}})$

Procedures

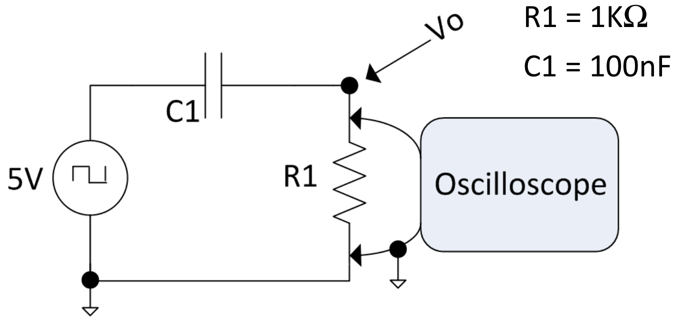
1. Use the RLC meter to measure the capacitance of C1. Compare the marked value and the measured value. What is its tolerance? ~20%

   Note: 97.45 nF.

   - The maximum tolerance of capacitors may be +80%, -20%.
   - https://www.arrow.com/en/research-and-events/articles/guide-to-capacitor-codes-and-tolerance-code-chart

2. Set the Signal Generator output to 5Vp-p (peak-to-peak), 2.5V DC offset, Square wave with 1KHz. It must be a 50% periodic pulse swinging between 0V and 5V.
3. Build the circuit on the breadboard.
4. Measure the voltage $\mathbf{V_o}$ across C1 with an oscilloscope. Record your measurement and notice the changes when the input square wave is at its rising and falling edges.
5. Repeat step 4 with R1 = 10 KΩ (10 times of the previous value).

6. Interchange the connection of R1 and C1 as shown:



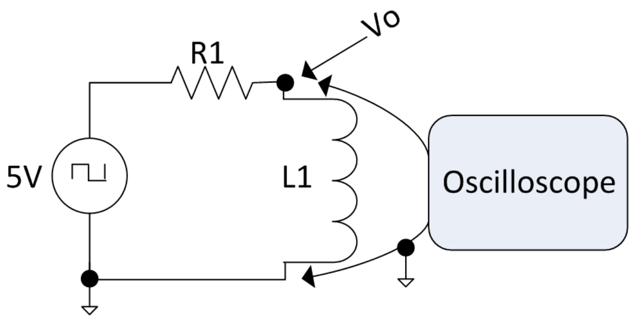
   Measure the voltage $\mathbf{V_o}$ across R1 with an oscilloscope. Record your measurement.

   Note:

   - Due to grounding problem, you cannot measure floated component with a grounded oscilloscope.

7. Repeat step 6 with R1 = 10 KΩ (10 times of the previous value)
8. Explain your observed results with the charging and discharging equations.
9. What theories (see Experiment-1) can be applied to explain your results?

Experiment 2.3: Transient signal to RL circuit



R1 = 1KΩ

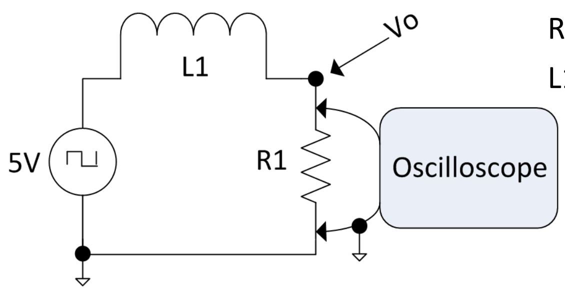
L1= 3.3mH

Now, C1 in the circuit of Experiment 2.2 is replaced with an inductor L1, as shown.

Procedures

marked: 3.3mH
measured: 3.358 mH.

1. Use the RLC meter to measure the inductance of L1. Compare the marked value and the measured value. What is its tolerance?
2. Set the Signal Generator output to 5Vp-p (peak-to-peak), 2.5V DC offset, Square wave with 1KHz. It must be a 50% periodic pulse swinging between 0V and 5V.
3. Build the circuit on the breadboard.
4. Measure the voltage $\mathbf{V_o}$ across L1 with an oscilloscope. Record your measurement and notice the changes when the input square wave is at its rising and falling edges.
5. Repeat step 4 with R1 = 10 KΩ (10 times of the previous value).
6. Interchange the connection of R1 and L1 as shown:



R1 = 1KΩ

L1 = 3.3mH

Measure the voltage $\mathbf{V_o}$ across R1 with an oscilloscope. Record your measurement.

7. Repeat step 6 with R1 = 10 KΩ (10 times of the previous value)
8. Explain your observed results with the charging and discharging equations.
9. What theories (see Experiment-1) can be applied to explain your results?
10. Conclude and compare the observations in both Experiments 2.2 and 2.3.

Experiment 2.4: AC signal to RC circuit

Sinusoidal wave is a special periodic signal, which has a single frequency component only. It is commonly used to test the frequency response of a circuit. Reactance component is frequency dependent. The impedance of the reactance component changes relative to the signal frequency. We are going to investigate the phase (θ) shifting and the transfer function (Vo/Vi) of this RC circuit.

Notes:

- Current and voltage are in-phase at resistor.
- Current and voltage have phase shift at reactance component (capacitor/inductor).
- Transfer function, the relationship between OUTPUT to INPUT, that represents the performance of the circuit.
  - GAIN, transfer function larger than 1.
  - LOSS, transfer function less than 1 (0~1).
  - 180 degree out of phrase, transfer function is negative.
- Phase difference is represented with complex number (REAL and IMAGINARY part).
- Engineers use X and Y Graph (OUTPUT against INPUT) to represent the relationship between output and input, Y-axis is output and X-axis is input.
- Use log scale on X and Y axes can reduce the length of axis, one axis in log scale is named semi-log, and both axes in log scale is named full-log. Electronics Engineers use semi-log paper to plot OUTPUT against FREQUECNY normally.
- Bold plot means two plotting lines on one X-Y graph to represent two relations they are related; GAIN against frequency and PHASE SHIFT against frequency.
- 1-3-6 scale means do measurement at frequency at 1 (log1=0), 3 (log3=0.5), 6 (log6=0.75), 10(log10=1), 30(log30=1.5), 60(log60=1.75), etc. All points at 3, 6, 10 represent +0.5, +0.75 and +1. Then, you can draw the frequency response (X-Y graph against frequency) with a white paper, no semi-log paper is needed.
  - 3(log3-0.5), center point (half) between 0 and 1.
  - 6(log6=0.75), center point (halt) between 3 and 10.
- Semi-log paper: https://www.eeweb.com/tools/semi-log-graph-paper/
- Bode plot: https://en.wikipedia.org/wiki/Bode_plot
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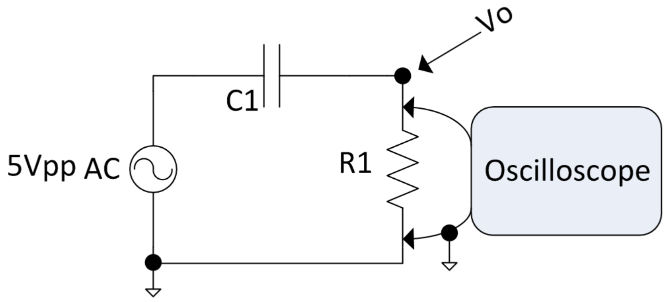
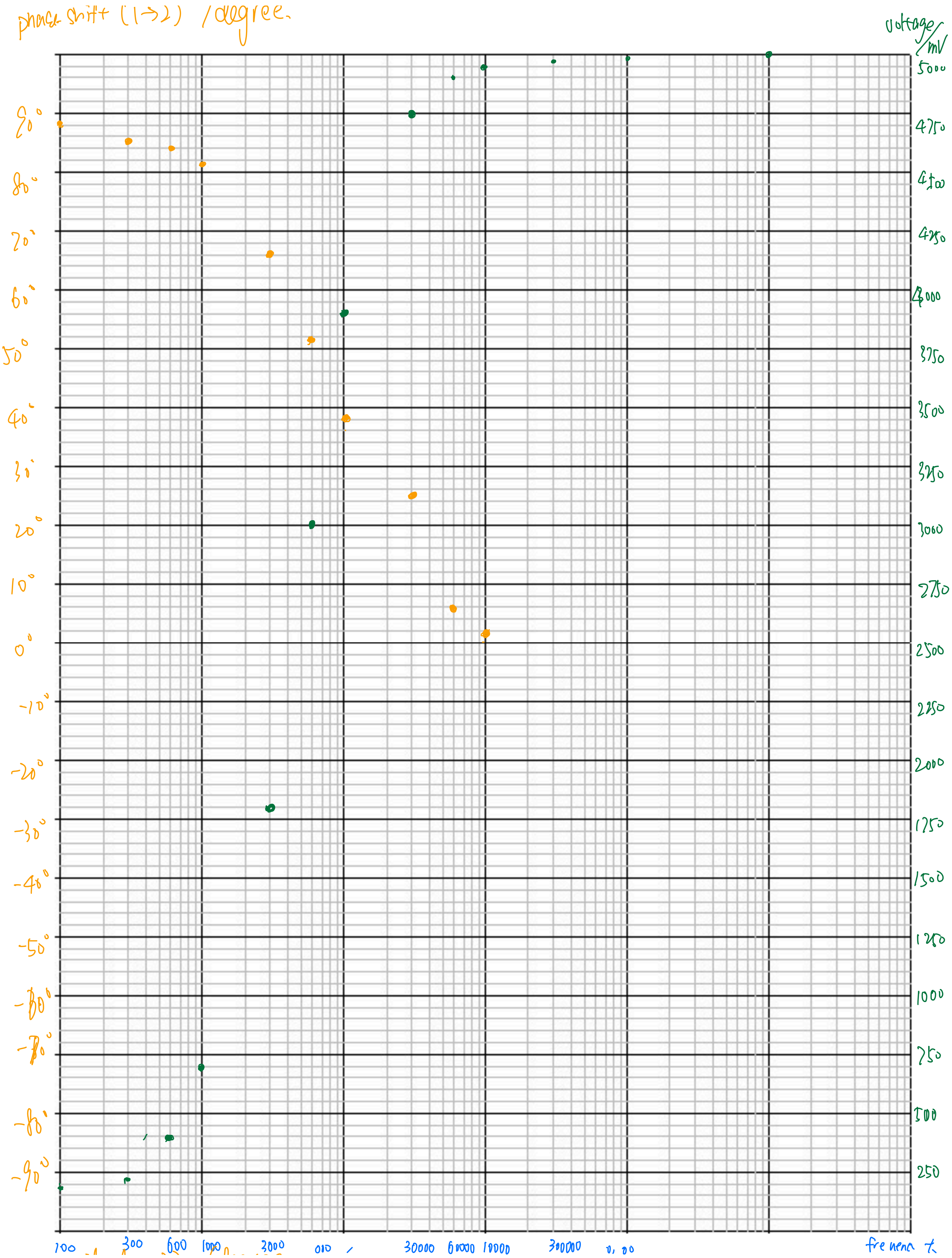


R1 = 10KΩ
C1 = 2.2nF
Frequency=100Hz~1MHz in log scale.

Procedures

1. Set the Signal Generator output to 5Vp-p (peak-to-peak), 0V DC offset, Sinusoidal wave, frequency from 100Hz to 1MHz with 1-3-6 step as log scale. Reduce the step size, in case you need data with finer frequency resolution.
   Note:
   - Engineers use ,
2. Connect the circuit on the breadboard.
3. Measure the voltage V_o across R1 and the phase shift between the source (input AC signal) and the voltage V_o across R1, under different input signal frequencies, with an oscilloscope. Record the measured waveform and the phase shift against frequency on semi-log scale.
4. Interchange the positions of R1 and C1, measure the voltage V_o across C1 and the phase shift between the source (input AC signal) and the voltage V_o across C1, under different input signal frequencies, with an oscilloscope. Record the measured waveform and the phase shift against frequency on semi-log scale.
5. Compare the results obtained in Step 3 and Step 4.
6. Conclude your observed results about the phase shift and the transfer function of the capacitor.

green: voltage. (amplitude : peak to peak)
orange: phase - ~~diff~~ shift


phase shift (1→2) /degree
voltage/mV
90°
80°
70°
60°
50°
40°
30°
20°
10°
0°
-10°
-20°
-30°
-40°
-50°
-60°
-70°
-80°
-90°
5000
4750
4500
4250
4000
3750
3500
3250
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2750
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2250
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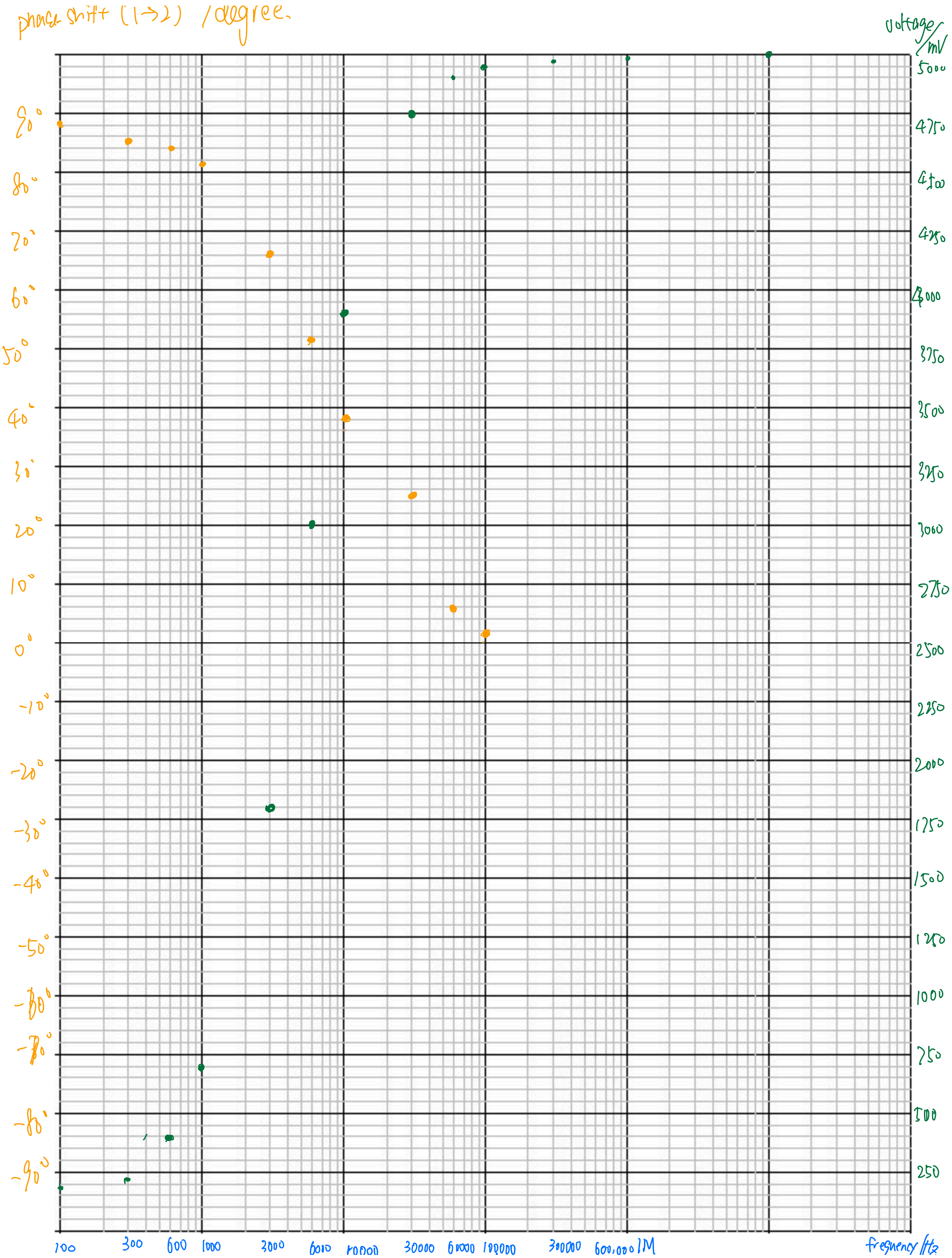
300000
frequency


phase shift (1→2) / degree
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90°
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1750
1500
1250
1000
750
500
250
100
300
600
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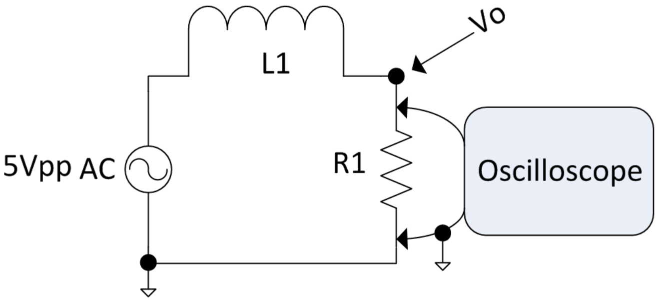
3000
6000
10000
30000
60000
100000
300000
600,000
1M
frequency/Hz

Experiment 2.5: AC signal to RL circuit



R1 = 150Ω

L1 = 3.3mH

Frequency=1KHz~1MHz

Now, we are going to investigate the phase (θ) shifting and the transfer function (Vo/Vi) of this RL circuit.

Procedures

1. Set the Signal Generator output to 5Vp-p (peak-to-peak), 0V DC offset, Sinusoidal wave, frequency from 1KHz to 1MHz with 1-3-6 step as log scale. Reduce the step size, in case you need data with finer frequency resolution.
2. Connect the circuit on the breadboard.
3. Measure the voltage V_o across R1 and the phase shift between the source (input AC signal) and the voltage V_o across R1, under different input signal frequencies, with an oscilloscope. Record the measured waveform and the phase shift against frequency on semi-log scale.
4. Interchange the positions of R1 and L1, measure the voltage V_o across L1 and the phase shift between the source (input AC signal) and the voltage V_o across L1, under different input signal frequencies, with an oscilloscope. Record the measured waveform and the phase shift against frequency on semi-log scale.
5. Compare the results obtained in Step 3 and Step 4.
6. Conclude your observed results about the phase shift and the transfer function of the inductor.
7. Compare the results obtained in Experiments 2.4 and 2.5, in terms of the differences of the phase shift between capacitor and inductor.

Experiment 2.6: AC signal to RLC series circuit

We know that capacitor and inductor are non-resistance components. We use impedance Z, instead of resistance R, to represent its characteristics. Z is the vector sum of reactance and resistance. In a LC circuit, a special case, when the reactance of both components will be cancelled out at the resonance frequency. In this experiment, we try to find the resonance condition and the resistances of LC components.

In real world, capacitors and Coil are not idea, they have internal resistance (in series) and conductance (in parallel). Q factor is the parameter to represent those characteristics and influence. Reactance components are frequency dependent, the Q factors are just for certain frequencies.

Note: In this experiment, we need to measure the voltages across each component. Oscilloscope and Signal Generator are both grounded equipment. It is impossible to measure the floated components with a grounded equipment. The currents passing through the three components connected in series are the same. Therefore, changing the connection sequence of the components will not affect the current. Thus, we have to measure the voltages across these three components with three different circuits.

Hint: Wrong connection of the oscilloscope shorts the signal to ground.

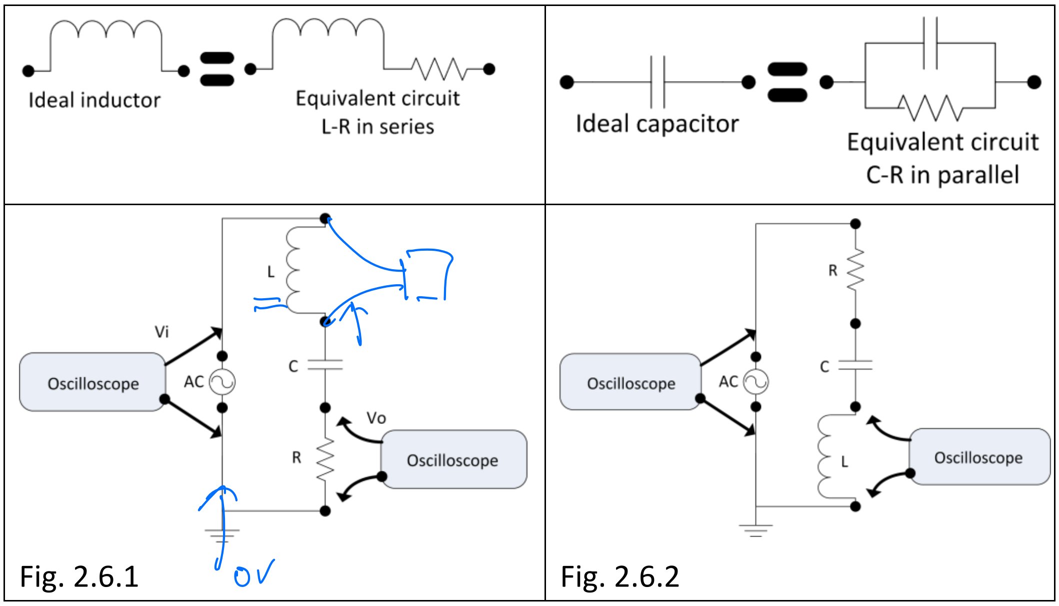


Fig. 2.6.1 Fig. 2.6.2

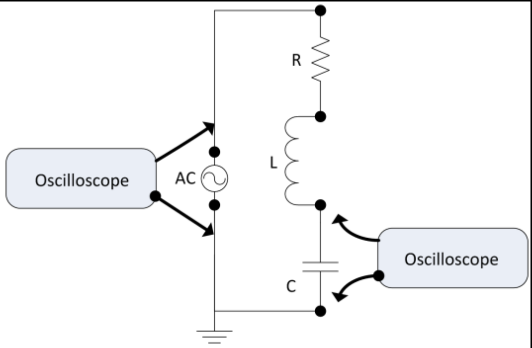


Fig. 2.6.3

L = 3.3mH
R= 390 ohm
C = 100nF

Procedures:

Note:

- If you ask which frequency should you measure. Find the frequency range you are interested (e.g. try 1Hz, 10Hz, 100Hz, 1KHz, 10KHz, etc.)
- Interesting frequency range means that has significant effect.
- Find the peak of effect and both sides (up slope and down slope) of the peak until the frequency meaningless (-3dB = half power).

1. Set the Signal Generator output to 5Vp-p (peak-to-peak), 0V DC offset, 1KHz sinusoidal wave.
2. Connect the circuit as shown in Fig. 2.6.1. Measure the voltage across the resistor R to find the interesting range.
3. Measure the V_o, V_i and the phase shift between the source (input AC signal) and the voltage V_o across R, with 1-3-6 log scale from input frequencies of 100Hz to 300KHz, <u>including the case with zero phase shift</u>.
4. Plot the graph of V_o / V_i against frequency and the phase against frequency. <u>Conclude your results</u>.

Experiment 2.7: Vector sum of RLC series circuit

From Experiment 2.6, we know the resonance frequency of these components connected in series. We will study to present the conditions (non-resonance) with vector sum has negative and positive phase shift.

Procedures

1. Set the Signal Generator output to 5Vp-p (peak-to-peak), 0V DC offset, Sinusoidal wave. Frequency is set at the value corresponding to -25-degree phase shift from your results obtained in Experiment 2.6.
2. Measure the voltages and the phases of R, L and C as Figs. 2.6.1, 2.6.2 and 2.6.3, respectively.
3. Draw the vectors of R, L, C and the sum on a single vector diagram.
4. Repeat Steps 1 to 3 at another input frequency which corresponds to +40-degree phase shift.

Experiment 2.8: Vector sum and internal resistance of L in RLC series resonance circuit

From Experiment 2.6, we know the resonance frequency of these components in series. Now, we try to find the internal resistance of the inductor.

Note: If the measured results are not good enough on oscilloscope, try to use DMM instead. Although DMM at high frequency is not good enough, the loss is the same at any special frequency. We are interested in the ratio of the results between different components.

Procedures

1. Set the Signal Generator output to 5Vp-p (peak-to-peak), 0V DC offset, Sinusoidal wave. Set the frequency at resonance condition.
2. Use a 100-ohm resistor instead of the 390 ohm resistor (the result will be significant).
3. Measure the voltages and the phases of R, L and C as Figs. 2.6.1, 2.6.2 and 2.6.3, respectively.
4. Draw the vectors of R, L, C and the sum on a single vector diagram.
5. Calculate the internal resistance of the inductor from your measured results.
6. Measure the resistance of the inductor with a DMM and an LRC meter.
7. Compare and conclude your three measured results (DMM, LRC meter and resonance circuit) about the internal resistance of the inductor.

Experiment 2.9: Voltage and Current characteristics of diode

A diode is made with a P-N junction, which has unidirectional characteristic. Current can pass through from Anode to Cathode only (forward current). Fig.2.9.1 shows Diode 1N4148.

Note:

- Using saw-tooth wave in this experiment that can easy to identify the voltage changes from negative to positive.
- Use two channels of oscilloscope for Vo and Vi, and overlap them to find out the relationship (transfer function).

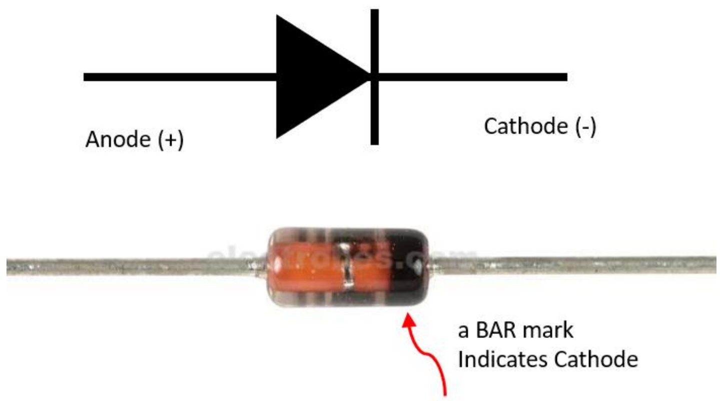


Fig. 2.9.1 1N4148 diode

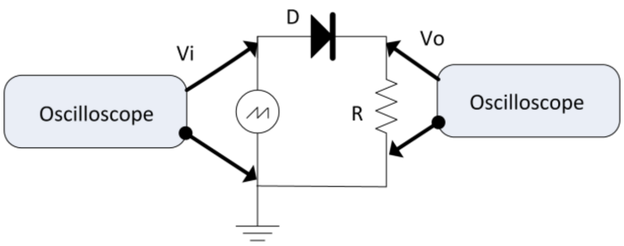


Fig. 2.9.2

D = 1N4148

R = 10K ohm

Signal Generator:

Frequency = 30KHz,

Saw-tooth wave, -2V to +2V

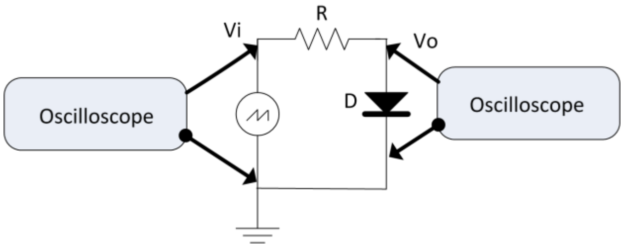


Fig. 2.9.3

D = 1N4148

R = 10K ohm

Signal Generator:

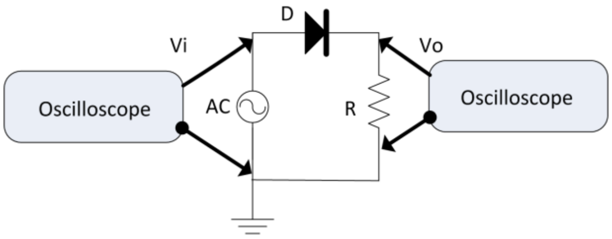
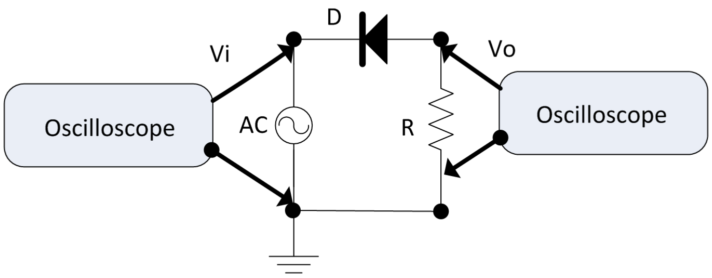
Frequency = 30KHz,

Saw-tooth wave, -2V to +2V

Procedures

1. Setup the circuit as Fig. 2.9.2.
2. Measure the values of V_o and V_i at different input voltages and record the waveforms of V_o and V_i.
3. Setup the circuit as Fig. 2.9.3. (due to oscilloscope is grounded equipment)
4. Measure the V_o and V_i at different input voltages. Sketch the relationship between V_o, V_i and current. (Hints: You have to use voltage which across the resistor to find the current)
5. Conclude your results.

Experiment 2.10: Unidirectional characteristics of diode

 Fig. 2.10.1	D = 1N4148 R = 10K ohm Signal Generator: Frequency = 30KHz, Sine wave, -2V to +2V
 Fig. 2.10.2	D = 1N4148 R = 10K ohm Signal Generator: Frequency = 30KHz, Sine wave, -2V to +2V

Procedures

1. Setup the circuit as Fig. 2.10.1. Record the waveforms of V_o and V_i.
2. Setup the circuit as Fig. 2.10.2. Record the waveforms of V_o and V_i.
3. Conclude the results of these two circuits and compare to exerpiment-2.9.

Experiment 2.11: Half wave rectifier circuit.

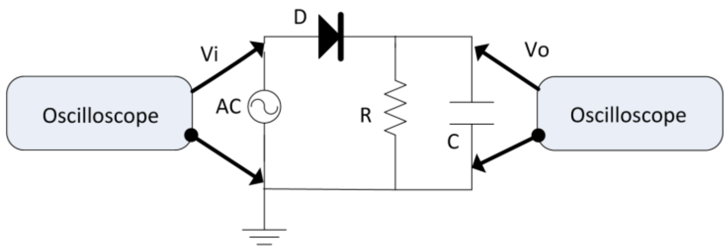


Fig. 2.11.1

D = 1N4148

R = 10K ohm

Capacitor = 1nF, 10nF and 100nF.

Signal Generator:

Frequency = 30KHz,

Sine wave, -2V to +2V

Procedures

1. Setup the circuit as Fig. 2.11.1.
2. Record the waveforms of V_o when C=1nF, 10nF and 100nF.
3. Conclude the function of the capacitor in the circuit.

Experiment 2.12: Bridge rectifier circuit.

In this experiment we need a floated source, so we use a 1:1 transformer to isolate the grounded signal generator.

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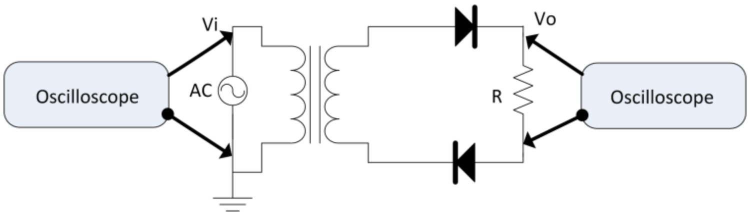
<tr><td>

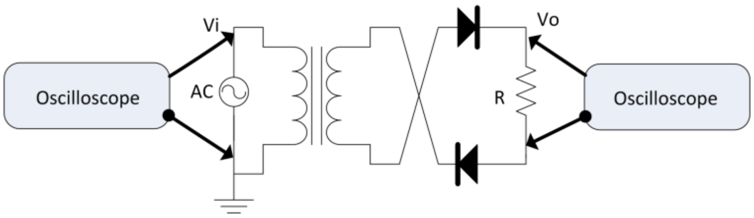
Fig. 2.12.1</td><td>D = 1N4148
R = 10K ohm
Signal Generator:
Frequency = 30KHz,
Sine wave, -2V to +2V</td></tr>
<tr><td>

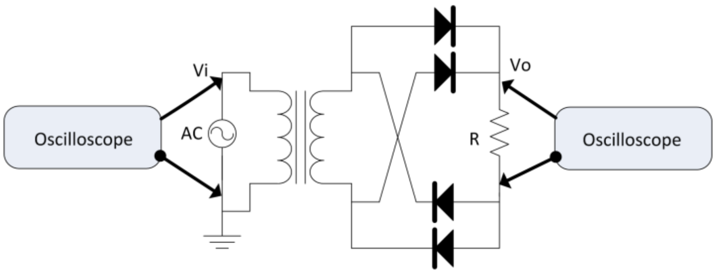
Fig. 2.12.2</td><td></td></tr>
<tr><td>

Fig. 2.12.3</td><td></td></tr>
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Procedures

1. Setup the circuit as Fig.2.12.1. Record the waveforms of V_o and V_i.
2. Setup the circuit as Fig.2.12.2. Record the waveforms of V_o and V_i.
3. Conclude the results of the two circuits.
4. Setup the circuit as Fig.2.12.3, which combines Fig.2.12.1 and Fig.2.12.2. Record the waveforms of V_o and V_i.
5. Explain how the bridge circuit works.

~ END ~