LAB 9 - ALTERNATING CURRENT RC CIRCUITS(TPL2)

Objectives

- Investigate voltage magnitudes across capacitors and resistors in AC circuits
- Investigate phase shifts between the voltages in AC circuits

Preliminary activities

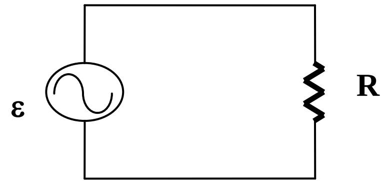
1. Prepare equipment. Plug the two voltage probes through two USBLink to the experiment laptop (please follow the instructions in Blackboard). Start the DataStudio software.

2. Load the experiment file. Download the DataStudio file **`Lab09_AC_RC.ds`** from the lab schedule webpage, and open it in DataStudio.

Introduction

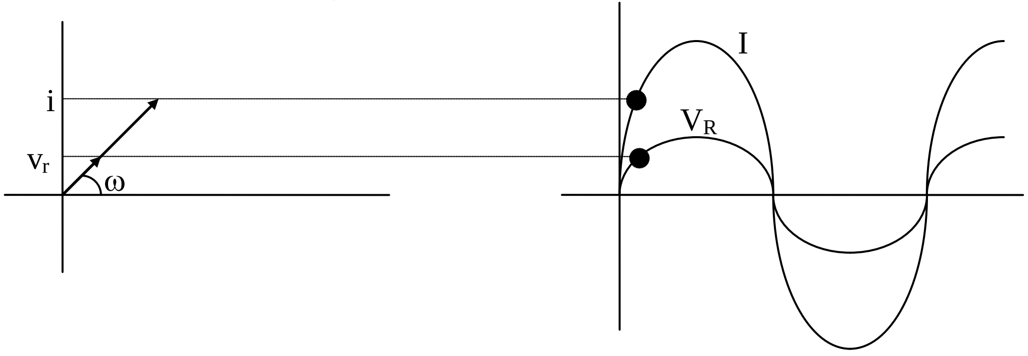
Up until now we have studied DC (direct current) circuits involving a constant current from a battery or power supply. The electrical circuits that most devices work on is AC (alternating current). The voltage in the device (and thus the current through the device) varies sinusoidally with time - with a frequency of 60 Hz (cycles per second). So the current goes from a positive peak (indicating a particular direction in the circuit) to a negative peak 120 times a second. This alternating current and voltage allow motors to run (an interaction between the current in a loop of wire and the magnetic field that it rotates within).

Resistive AC circuit:



Suppose an AC voltage is applied across a resistor as shown in the diagram. There will be a current in the circuit that is also sinusoidal. At any given moment in time, the voltages across all the elements in a circuit loop must sum to zero. In this case, that makes the voltage across the resistor (V_R) the same as the voltage from the generator (ε). The current in this circuit is said to be *in phase* with the voltage across the resistor as indicated in the graph below.

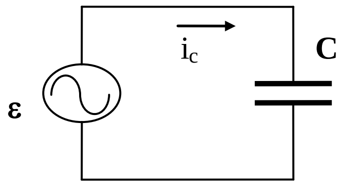
A vector called a *phasor* can represent each, the current through, and the voltage across the resistor. Vectors that rotate counter-clockwise around the origin indicate the current and the voltage across the resistor. At any given instant in time, the component of the particular vector along the vertical axis indicates the magnitude of the variable at that time.

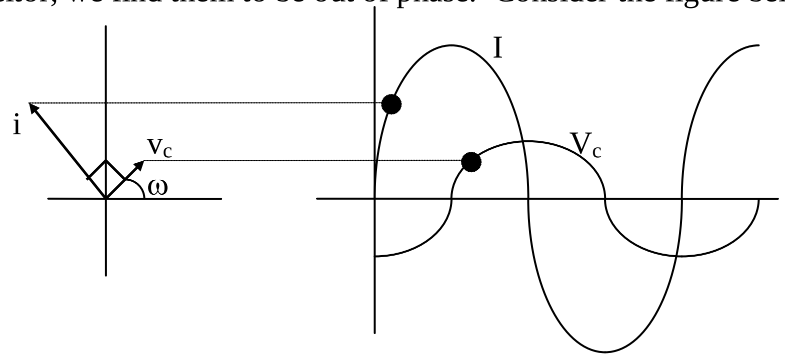


So, the current at that moment in time (i) is the vertical component of the I vector which rotates with an angular frequency ω. The voltage across the resistor (v_r) at that moment is the vertical component of the V_R vector that rotates with an angular frequency ω.

Capacitor AC Circuit

When a current flows in a circuit containing a capacitor, the capacitor will accumulate charges on the plates and this will create a voltage across the plates of the capacitor. But, when we look at the vectors for the current and the voltage across the capacitor, we find them to be out of phase. Consider the figure below:

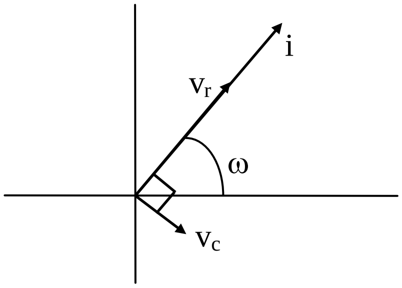


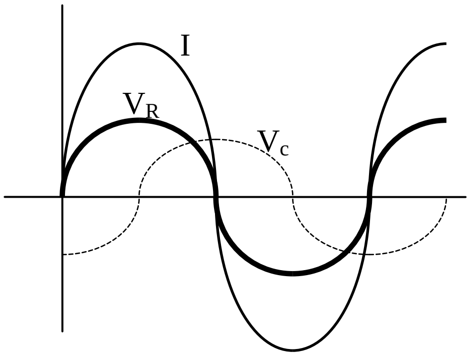


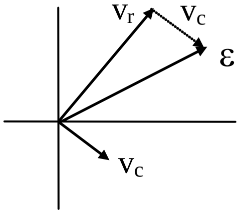
In this case, the current *leads* the voltage across the capacitor (that is, the current will peak first, then the voltage across the capacitor will peak). Let's see why that is ... assume that you have an uncharged capacitor and the voltage from the generator is a maximum - there will be a maximum current. But that current will start to charge up the capacitor. That charge increases as the current starts to drop off and the voltage across the capacitor starts to rise. When the current reaches zero, the voltage across the capacitor reaches a maximum. Now the current starts to peak in the negative direction, which means the capacitor will start to discharge, thus its voltage starts to drop. This cycle continues like that with the current leading the voltage across the capacitor by 90 degrees or 1/4 cycle. They are out of phase by 90 degrees.

Resistive and Capacitive Circuit

Let's put these two cases together. If you have a circuit that has a resistor and a capacitor in series, the current will be in phase with the voltage across the resistor, but out of phase (by 90 degrees or 1/4 cycle) with the voltage across the capacitor. The current (and thus the voltage across the resistor) will lead the voltage across the capacitor by 1/4 cycle. We can put the three vectors (I, V_R, V_C) together as shown on the left below.





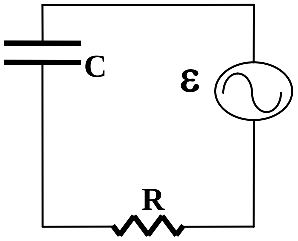


Because of the combination of the resistor and the capacitor in the circuit, a phasor vector as shown in the third figure above can represent the voltage across the entire circuit. Note that this vector is the vector that would give a curve equal to the sum of the two sine waves for the voltage across the capacitor and the voltage across the resistor.

RC Circuit summary

- The voltage across the resistor leads the voltage across the capacitor by 90 degrees.
- There is a phase angle between the main voltage (*E*) and the voltage across the resistor (Φ_{ER}).
- There is a phase angle between the main voltage (*E*) and the voltage across the capacitor (Φ_{EC}).
- The phase angle Φ_{ER} and phase angle Φ_{EC} add up to 90 degrees or 1/4 cycle (for RC circuits) ($\Phi_{RC}=90^0$)
- The voltages in the circuit form a Pythagorean relationship: $E^2 = V_R^2 + V_C^2$

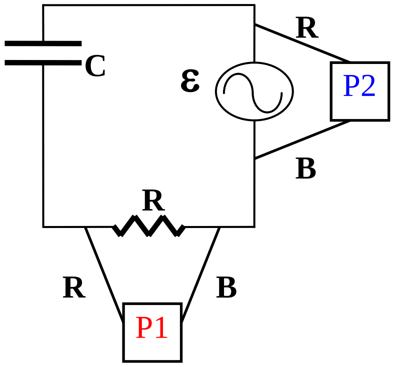
Circuit connections



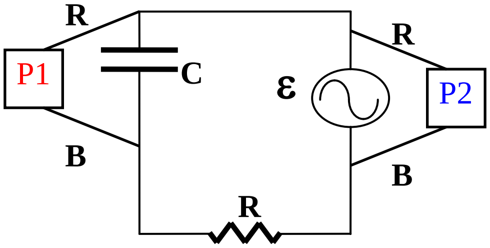
There is one main series circuit that we are dealing with. There is a main voltage (*E*) across the transformer, a voltage across the resistor (V_R), and a voltage across the capacitor (V_C). The circuit should be set up in that clockwise order as shown to the right.

When we make sensor connections to the circuit - we have to make them with the probes (the red and black sides of each probe) in a particular order relative to the other elements. [This is necessary to make sure that they are in the proper time "order" to be able to measure the phases - if the probes are reversed from the proper order, that's equivalent to shifting the voltage curve by 180 degrees that will interfere with the way we are measuring the phases!] The correct order (depending on what measurements are being made) is shown below:

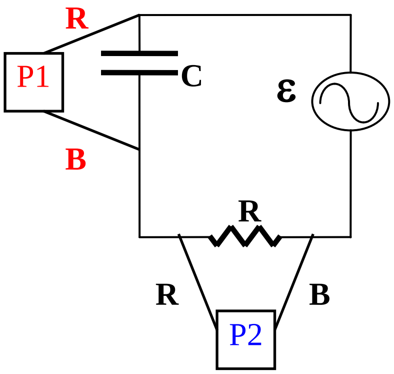
Circuit A - *E* and V_R



Circuit B - *E* and V_C



Circuit C – V_C and V_R



It is very important when you use a particular circuit to make sure the probe colors are matched exactly as shown in the diagrams above - otherwise the phase readings will be affected.

For the capacitor in the circuit, we will use a **10-microfarad** capacitor. Since we want to be able to change the resistance in the circuit, we will use a decade resistance box for the resistor R. The input voltage comes from the transformer (a step-down transformer to convert the 120 volts of wall voltage to a usable smaller voltage).

Part 1 - Investigating the effect of changing the Resistance on V_R and Φ_{ER}

1. Set up circuit A. Setup the components in the series circuit, and then attach the probes as shown in circuit A from the previous section. Set the decade box to 0 ohms. DataStudio should be displaying both Voltage 1 (in this case the V_R) and Voltage 2 (in this case *E*) and the time axis shows 0.04 seconds.

2. Start graphing. Click START to start the graphing process. The data-rate is high, so the data might not show up in real time. After a slight delay, the graph should appear on the screen. Both voltages are being measured, but you will probably only see one show up – Voltage 2 (blue) - the voltage across the whole circuit. Since the resistance is zero, there should be no voltage across the resistor.

3. Changing the resistance. Using the switches along the bottom row of the decade box (the “four” row - 4 Ω, 40 Ω, 400 Ω, etc.) we can increase the resistance and notice the effect on the curves (and on the phase shift between them). Try 4 ohms, press START to see the graph. Then try 40 ohms (remember to switch the 4 off again), and graph it. Try 400 ohms. Try 4000 ohms (4 k). Try 40k ohms. At this point, the two curves should be basically lined up. This is mostly a resistive circuit (the effect of the capacitor is so small compared to the resistor that it is hard to tell the difference between the main voltage and the voltage across the resistor). [You might notice a small phase shift between the graphs. The resistors have a little bit of inductance to them, causing a small phase shift.]

Questions Answer the questions on the Data/Question sheet for this section.

Part 2 - Investigating the effect of changing the Resistance on V_C and Φ_{EC}

1. Set up circuit B. Set up the components in the series circuit, and then attach the probes as shown in circuit B from the previous section. Set the decade box to 0 ohms. Note the new variables being plotted on the graph: Voltage 1 is now V_C, and Voltage 2 is now *E*.

2. Start graphing. Click START to start the graphing process. Since the resistance is zero, there should be no voltage across the resistor and thus basically all of the voltage is across the capacitor.

3. Changing the resistance. Using the switches along the bottom row of the decade box (the “four” row) we can increase the resistance and notice the effect of the curves (and on the phase shift between them). Try 4 ohms, click START to see the graph. Then try 40 ohms (remember to switch the 4 off again), and graph it. Try 400 ohms. Try 4000 ohms (4 k). Try 40k ohms.

Questions Answer the questions on the Data/Question sheet for this section.

Part 3 - Investigating the effect of changing the Resistance on V_C and V_R and Φ_{RC}

1. Set up circuit C. Set up the components in the series circuit, and then attach the probes as shown in circuit C from before. Set the decade box to 0 ohms. Note the new variables being plotted on the graph: Voltage 1 is now V_C, and Voltage 2 is now V_R.

2. Start graphing. Click START to start the graphing process. Since the resistance is zero, there should be no voltage across the resistor and thus basically all of the voltage is across the capacitor.

3. Changing the resistance. As in the previous sections, vary the resistance from 0 to 40K ohms and notice the changes in the graphs. Go back to 400 ohms and answer the questions on the Data Question sheets.

Questions Answer on the Data/Question sheet for this section.

Part 4 - Investigating the voltage magnitudes

1. Load the Excel template. We will use Excel to make a graph based on the voltage measurements we make. The Excel sheet can be found on the Lab Schedule page. Open it and then save it and change the name (to preserve the original) – this will be your working copy.

2. Setup. Disconnect the voltage probes from the Circuit. We want to measure the voltages with the multimeter. Set the multimeter to measure the AC voltage (the setting with the “sine curve”). Again, it will be much easier to attach the meter across a particular element (resistor, capacitor, power supply) and then run through all the resistances. When finished, switch to a new element, and repeat. Start with the power supply voltage (V(tot)). (You should find this to be basically the same for all the resistances - the transformer supplies a fixed peak voltage to the circuit.) You may notice that the numbers seem to be smaller than what the screen showed. That’s because the meter is giving an “average” value called the root-mean-squared (RMS) value - which is the peak voltage divided by the square root of 2. For our purposes, we can just record this value for the voltage and use it in our calculations. Record the voltage values in the chart on the Data/Question sheet.

3. V_C and V_R. Repeat the above procedure to get the voltages across the capacitor and the resistor with the changing resistance values.

4. Inputting numbers. The voltage numbers for the chart (Part 4) should be put into the spreadsheet - the rest of the spreadsheet contains calculations that are already in place. There is a graph for the voltages across each of the elements, as a function of the resistance.

5. Print graph page. When you are finished inputting the numbers print that page to be included with the lab report. (Make sure you try the Print Preview to make sure you have only one page [with all the important parts] printed. The “print area” has been pre-set, but double-check it.)

Part 5 - Final calculations

We want to check to see if the numbers we have make sense based on the theory presented in the Introduction. The squares of the V_C and V_R should equal the square of the *E*. We have all the raw data, we want an easy way to compare these numbers. There is a spreadsheet template that will help us make the final comparisons.

Questions Answer on the Data Question sheet:
Pick three rows (near beginning, in middle, and near end) in the chart of Part 4. Show sample calculations to answer the following questions:

Do the resistor and capacitor voltages add up algebraically to the total voltage (if not, why not?) – how should we attempt to add them (hint: should they be considered “vectors”?). Prove that the voltage data in each row is reasonable, if we “add” them the right way.

FINAL NOTE-TRANSFER ALL SAVED FILES TO YOUR OWN LAPTOP

DATA/QUESTION SHEET FOR LAB 9 - AC - RC CIRCUITS

Part 1 - Investigating the effect of changing the Resistance on V_R and Φ_{ER}

3. Changing the resistance. Using the switches along the bottom row of the decade box (the "four" row - 4 Ω, 40 Ω, 400 Ω, etc.) we can increase the resistance and notice the effect on the curves (and on the phase shift between them). Try 4 ohms, press START to see the graph. Then try 40 ohms (remember to switch the 4 off again), and graph it. Try 400 ohms. Try 4000 ohms (4 k). Try 40k ohms. At this point, the two curves should be basically lined up. This is mostly a resistive circuit (the effect of the capacitor is so small compared to the resistor that it is hard to tell the difference between the main voltage and the voltage across the resistor). [You might notice a small phase shift between the graphs. The resistors have a little bit of inductance to them, causing a small phase shift.]

Questions a) With the resistance set at 400 ohms, and the graph on the screen ... which graph is "leading" which? ["Leading": as you move along the time axis to the right, which graph peaks first, and then which peaks second?] (Remember that the BLUE line is the total voltage and the RED line is the voltage across the resistor). Is this reasonable based on the discussion in the introduction?

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b) How does the phase (the shift) between the graphs seem to vary as you increase the resistance (you don't have to measure anything, just by looking at the graphs) - are they getting closer together or farther apart as the resistance increases?

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Part 2 - Investigating the effect of changing the Resistance on V_C and Φ_{EC}

2. Start graphing.

Predictions a) What do you think the trend will be for the voltage across the capacitor (the magnitude), as you change the resistance?

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b) What do you think the trend will be for the phase shift between the total voltage and the capacitor voltage, as you change the resistance (think about what happened with the resistor)?

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3. Changing the resistance.

Questions c) With the resistance set at 400 ohms, and the graph on the screen ... which graph is "leading" which? (Remember that the BLUE line is the total voltage and the RED line is the voltage across the capacitor). Is this reasonable based on the discussion in the introduction?

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d) How does the phase (the shift) between the graphs seem to vary as you increase the resistance (you don't have to measure anything, just by looking at the graphs) - are they getting closer or farther apart as the resistance increases?

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Part 3 - Investigating the effect of changing the Resistance on V_C and V_R and Φ_{RC}

2. Start graphing.

Predictions a) What do you think the trend will be for the two voltages (magnitudes)?

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b) What do you think the trend will be for the phase shift between the resistor voltage and the capacitor voltage?

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3. Changing the resistance. As in the previous sections, vary the resistance from 0 to 40K ohms and notice the changes in the graphs. Go back to 400 ohms and answer the questions below:

Questions c) With the resistance set at 400 ohms, and the graph on the screen ... which graph is "leading" which? (Remember that the BLUE line is the voltage across the resistor and the RED line is the voltage across the capacitor). Is this reasonable based on the discussion in the introduction?

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d) How does the phase (the shift) between the graphs seem to vary as you increase the resistance (you don't have to measure anything, just by looking at the graphs) - are they getting closer together or farther apart as the resistance increases?

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Part 4 - Investigating the voltage magnitudes

[Values of V(tot), V(R), and V(C) are in Volts]
[Values of R are in Ohms]

R	V(tot)	V(R)	V(C)
10			
20			
40			
80			
160			
200			
300			
400			
800			
1600			
2000			

Part 5 - Final calculations

Questions Pick three rows (near beginning, in middle, and near end) in the chart of Part 4. Show sample calculations to answer the following questions:

Do the resistor and capacitor voltages add up algebraically to the total voltage (if not, why not?) – how should we attempt to add them (hint: should they be considered “vectors” so that $V(tot)^2 = V(R)^2 + V(C)^2$?). Prove that the voltage data in each row is reasonable, if we “add” them the right way. You could show your work in the space below.

CALCULATIONS

Row near beginning. (R range 10Ω to 80Ω)

Row near middle. (R range 160Ω to 300Ω)

Row near end. (R range 400Ω to 2000Ω)

For “Row near middle”, calculate the % difference between V(tot) and the “sum” of V(R) and V(C). Use V(tot) = x_1 and $\sqrt{V(R)^2 + V(C)^2}$ = x_2 in the %diff formula.

Questions/Suggestions → James Nolta - jnolta@LTU.EDU