CG1111 Engineering Principles and Practice I

AC Circuit Principles I - Phasors

Week 6, Studio 1

Time	Duration (mins)	Activity
0:00	20	Briefing on activities
0:20	100	Activity #1: Performing voltage phasor measurements using BitScope, and verifying KVL for AC circuits
2:00	20	Activity #2: Performing AC circuit analysis using phasors and impedances

Introduction:

- The war between AC and DC was won by AC. Most of the electric power used today is AC. The appliances and equipment at our homes and work places are supplied by AC. So far, we have only learnt DC circuit analysis. It would be interesting to see if DC circuit analysis techniques are applicable to AC systems or not.

- In Activity #1, you will build a series RC circuit connected to a sinusoidal voltage supply. You will use BitScope to observe the voltage waveforms across each circuit element, from which you will see that their voltages are not in phase. From the BitScope measurements, you will first verify whether KVL works with RMS voltage values. After which, you will verify whether KVL works with voltage phasors. You will also practise drawing phasor diagrams.

- Analyzing AC circuits in the time domain is very tedious, as they result in complicated differential equations. A simpler approach is to enlist the help of complex numbers, which magically account for the phase differences of the various quantities. By representing sinusoids as "phasors", and representing resistance/inductance/capacitance as complex resistances known as "impedances", we can convert an AC circuit into an equivalent resistive circuit with DC sources. This allows us to use DC circuit analysis techniques that we are already familiar with. After obtaining the solution, we then convert them back to time-domain.

- In Activity #2, you will practise performing AC circuit analysis using phasors and impedances that you have derived in Activity #1. You will also try to estimate the capacitance of the given capacitor (which has a nominal value of 10 nF).

Objectives:

- To understand why we cannot ignore phase differences in AC circuits
- To learn how to perform phase measurements between signals
- To learn how to derive phasors from experimental measurements
- To practise drawing phasor diagrams
- To practise AC circuit analysis using phasors and impedances

Materials:

- Breadboard and connecting wires
- Digital multimeter
- BitScope
- Ceramic capacitor {10 nF (code 103)}
- 5% tolerance resistor {2.2 kΩ}

Activity #1: Performing voltage phasor measurements using BitScope, and verifying KVL for AC circuits (100 mins)

Procedure:

1. Connect BitScope's red-colour probe to its AWG pin. Next, connect four more probes to the CHA and CHB pins, as well as the two GND pins.

2. Using the breadboard, construct the RC circuit shown in Figure 1. Use your multimeter to measure the actual resistance of the 2.2 kΩ resistor and note down its value in your learning journal. The sinusoidal voltage source is implemented using BitScope's waveform generator. Use the AWG probe as the "+" terminal of the sinusoidal voltage source and connect CHA's probe to it as well. Next, use the GND probe below CHA as the "–" terminal of the sinusoidal voltage source. This will be regarded as the common ground in the circuit.

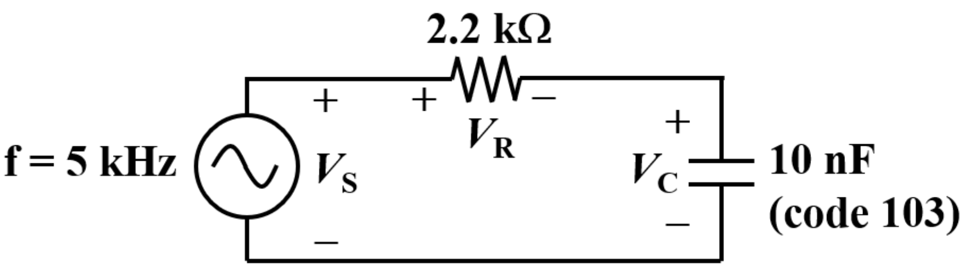


Figure 1: RC circuit powered by a sinusoidal source.

3. Run BitScope DSO on your computer. Turn on the power to your BitScope, and turn on its waveform generator by clicking on "WAVE" in the "Scope Selectors (2)" panel (see Appendix for its position). In the "FUNCTION GENERATOR" panel (top left), right-click on the frequency and select **5 kHz**. Check that the peak-to-peak voltage is set as **3.3 V**. For the DC offset (i.e., the box beside the peak-to-peak voltage setting), left-click it and drag its value downward to **0 V**. In the "Channel Controls (7)" panel, change the voltage per division of CHA to **500 mV/Div**.

4. Next, we will use BitScope's CHB to observe the capacitor's voltage V_C. The "+" and "–" polarities of V_C are as defined in Figure 1. (Note: the polarities here are meant for the voltage's definition; the ceramic capacitor itself does not have a preferred polarity.) Connect CHB's probe to the "+" polarity of V_C, and the GND probe to its "–" polarity. Turn on CHB in the "Channel Controls (7)" panel, and set its voltage per division to **500 mV/Div**.

5. We will now perform measurements for V_S on CHA. Click on "TRACE" in the "Timebase Control (6)" panel to freeze the waveforms. Turn on "CURSOR" in the "Scope Selectors (2)" panel. To measure the peak-to-peak voltage of V_S, click on "CHA" in the "Channel Controls (7)" panel, then right-click on the brown voltage box in the "Cursor Measurements (5)" panel to select "MAX". Right-click on the dirty-green box directly underneath the brown box, and select "MIN". The peak-to-peak voltage of V_S is now shown in the yellow box directly underneath the dirty-green box. You can obtain the amplitude of V_S as half of this peak-to-peak value. Also calculate its RMS value. Enter the above values into Table I below.
   Note: The measured peak-to-peak voltage of V_S is not 3.3 V that you have set in BitScope's function generator because the source has internal resistance, which causes the measured voltage to drop when there is current drawn.

Table I: Voltage measurements and corresponding phasor calculations

	Peak-to-peak (V)	Amplitude (V)	RMS (V)	Measured ΔT (μs) (leading or lagging V_S?)	Calculated phase angle (degrees)	Phasor (Amplitude $\angle$ Phase Angle)
V_S				---	0°	e.g., 1.54 $\angle$0°
V_C						
V_R						

6. Next, we will perform measurements for V_C on CHB. Click on "CHB" in the "Channel Controls (7)" panel. Notice that the cursors now automatically jump to the max and min of CHB's waveform. The peak-to-peak voltage of V_C is now shown in the **green** box directly underneath the dirty-green box. Calculate its amplitude and RMS values. Enter the above values into Table I as well.

7. We will now perform the phase angle measurement for V_C w.r.t. V_S (i.e., taking V_S as reference and assuming its phase angle is 0°). Figure 2 below explains how to tell whether a waveform is leading or lagging, and how to calculate its phase angle. In the example in Figure 2, CHA's waveform passes the horizontal axis earlier than CHB's waveform, meaning that CHB's waveform is lagging CHA's waveform. If CHA's waveform is taken to be the reference with a phase angle of 0°, then CHB's waveform has a phase angle of $-\frac{\Delta T}{T} \times 360°$, where T is the period and ΔT is the absolute value of the time difference between the two waveforms. Now, drag one of the two vertical cursors to the peak of V_S's waveform, and the other vertical cursor to the nearest peak of V_C's waveform. Note down ΔT (can be read from the cyan colour box in "Cursor Measurements (5)" panel) in Table I, indicating whether V_C is leading or lagging, and calculate V_C's phase angle.

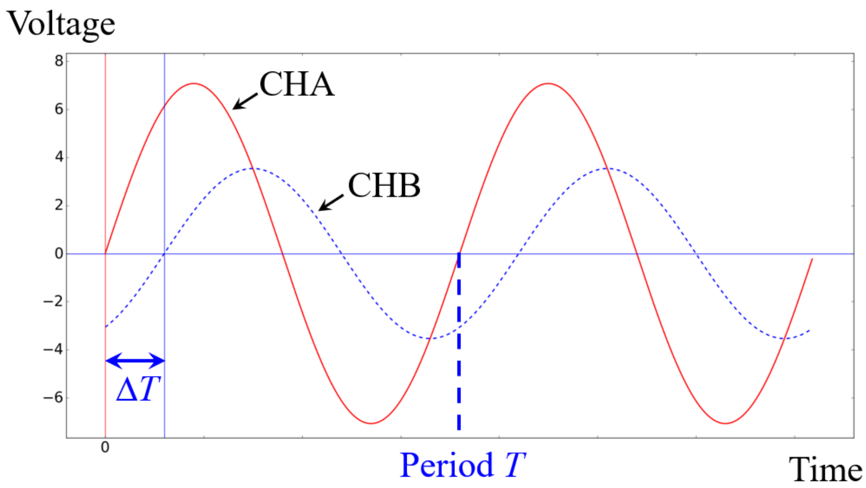


Figure 2: Phase measurement illustration

8. Next, we will perform measurements for the resistor voltage V_R. To do so, we need to first perform some rewiring to swap the position of the resistor and capacitor in the circuit. **Why do we need to swap the elements?** BitScope's CHA and CHB probes measure the voltage waveforms w.r.t. ground. (This is true for most other oscilloscopes too.) Hence, you cannot measure V_R unless one of the two ends of the resistor is connected to ground. Figure 3 below illustrates how you should connect your circuit when measuring V_R using CHB (while keeping CHA for measuring V_S).

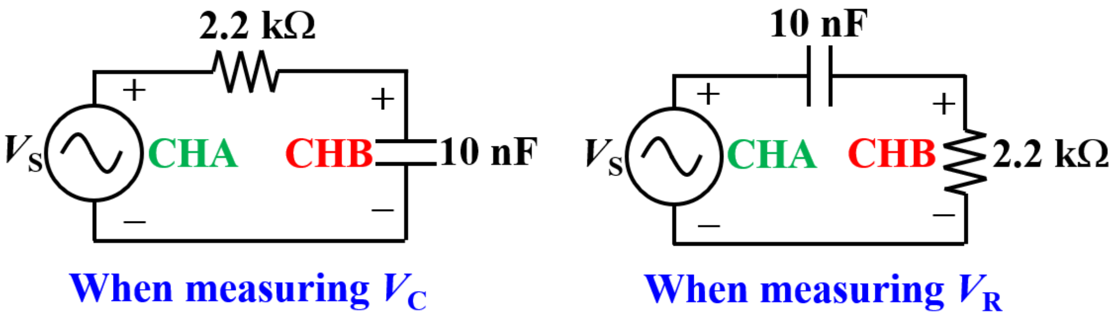


Figure 3: We need to swap the positions of the capacitor and resistor for measuring V_R.

9. Now, with CHB measuring V_R, repeat the procedure for measuring its peak-to-peak voltage, and then calculate its amplitude and RMS value. Also perform its phase measurement w.r.t. the supply voltage V_S. Write down all your results in Table I as well.

10. In the last column of Table I, write down the phasors for voltages V_S, V_C, and V_R.

11. Using the results in Table I, verify that KVL cannot be applied on RMS voltage values. Why?

12. Now, verify KVL in terms of the phasors. You need to use the COMPLEX function of your calculator. Compare phasor V_S with the sum of phasors V_R and V_C.

13. Draw the phasor diagram showing the three voltage phasors: V_S, V_C and V_R.

Activity #2: Performing AC circuit analysis using phasors and impedances (20 mins)

Introduction:

The resistor used in the previous activity has a 5% tolerance. Similarly, the ceramic capacitor used also has tolerance, which can be sometimes as high as 10-20%. In this activity, you will try to estimate its capacitance from the phasor measurements.

Procedure:

1. From the voltage phasors obtained in Activity #1, calculate the phasor for the current I_S in the circuit.

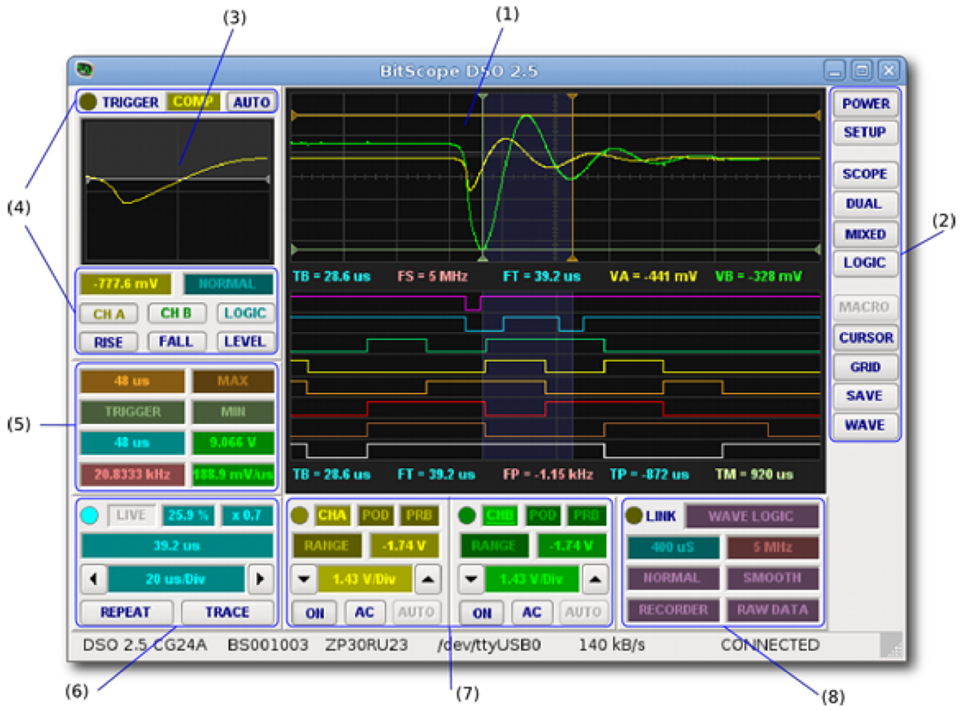
   Hint: The current is the same for all the three elements (sinusoidal voltage source, resistor, and capacitor) in the circuit, as they are connected in series. Use the actual resistance value you have measured in Activity #1 Step 2.

2. Assuming that the actual capacitance is C, write down the impedance Z_C of the capacitor in terms of C.

3. Using the capacitor's voltage phasor you have obtained from Activity #1, and also your answers from Steps 1 and 2 in Activity #2, estimate the value of the capacitance C. What could be the possible sources of experimental errors?

END OF STUDIO SESSION

APPENDIX: BITSCOPE DSO'S INTERFACE



ID	FEATURE	DESCRIPTION
(1)	Main Display	Waveform, logic and spectrum displays, measurements and cursors.
(2)	Scope Selectors	Virtual instruments, scope tools, presets, cursors, graticule etc.
(3)	Trigger Windows	Shows trigger levels, analog and logic waveforms at the trigger.
(4)	Trigger Controls	Controls trigger setup and displays trigger waveform and data.
(5)	Cursor Measurements	X and Y cursor values, voltage, time and rate measurements.
(6)	Timebase Control	Timebase, Zoom and Time Focus control parameters.
(7)	Channel Controls	Controls input source, range, vertical position and scaling.
(8)	Capture Control	Capture sample rate, duration, frame rate and display modes.