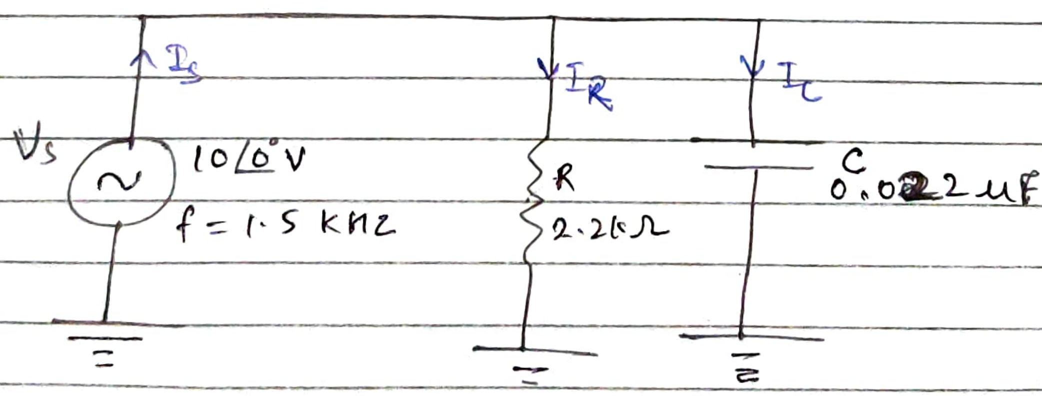
Name: Archit Agrawal
Student ID: 202052307

EE160: Experiment 2

Objective -: Design and simulate any three (of given 5) circuits in SPICE. Plot the voltages (across each element), currents (through each element), and total current. Find the phase difference between the source voltage (V_s) and all other voltages and currents from your simulations. Calculate these voltages and currents theoretically. Draw the phasor diagram from your theoretical calculations. Compare the theoretical results with the simulation results. Also, plot total power ($V_s \times I_{total}$) of the circuit.

Mathematical Expressions and Theoretical Calculations

CIRCUIT 1 -:



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$$Z_c = -jX_c$$

$$X_c = \frac{1}{\omega C} = \frac{1}{2\pi \times (1.5k) \times (0.022\mu)}$$

$$X_c = 4.825\,k\Omega$$

$$\therefore Z_c = -j(4.825k)\ \Omega$$

$$\bar{Z}_c = 4.825k\angle -90^\circ\ \Omega$$

$$\bar{Z}_R = 2.2k\angle 0^\circ\ \Omega$$

Since, R and C are in parallel with voltage source

$$\boxed{\bar{V}_s = \bar{V}_R = \bar{V}_c = 10\angle 0^\circ\ V}$$

$$\therefore \bar{I}_R = \frac{\bar{V}_R}{\bar{Z}_R} = \frac{10\angle 0^\circ}{2.2k\angle 0^\circ}$$

$$\boxed{\bar{I}_R = 4.545\angle 0^\circ\ mA}$$

and, $\bar{I}_c = \frac{\bar{V}_c}{\bar{Z}_c} = \frac{10\angle 0^\circ}{4.825k\angle -90^\circ}$

$$\boxed{\bar{I}_c = 2.073\angle 90^\circ\ mA}$$

Using KCL,

$$I_{tot} = I_c + I_R$$

$$I_{tot} = \{j(2.073) + 4.545\}\ mA$$

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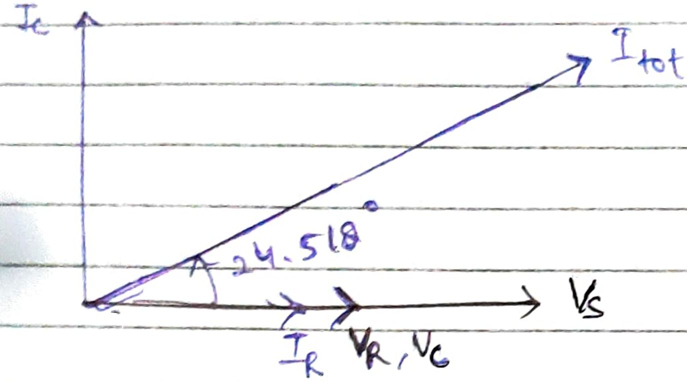
$$\boxed{\overline{I_{tot}} = 4.995 \angle 24.518^\circ \text{ mA}}$$

Phasor Diagram



Time Domain

Given $V_s = 10 \angle 0^\circ$ V

$\therefore V_{rms} = 10$ V

$\therefore V_m = 10\sqrt{2}$ V

In time domain, we write peak value;

$\therefore V_R = V_C = V_S = 10\sqrt{2} \sin(9420t + 0^\circ)$ V

$I_{tot} = 4.995\sqrt{2} \sin(9420t + 24.518^\circ)$ mA

$I_R = 4.545\sqrt{2} \sin(9420t + 0^\circ)$ mA

$I_C = 2.073\sqrt{2} \sin(9420t + 90^\circ)$ mA

The time domain graph just gives an idea of phase of V_s and I_{tot} and the magnitude of I_{tot} and V_{tot} is not implied by it.

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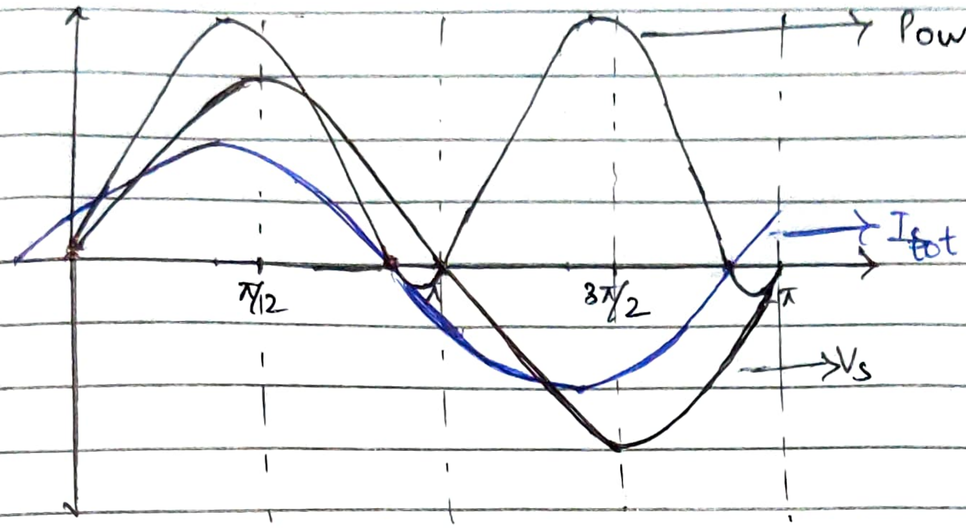
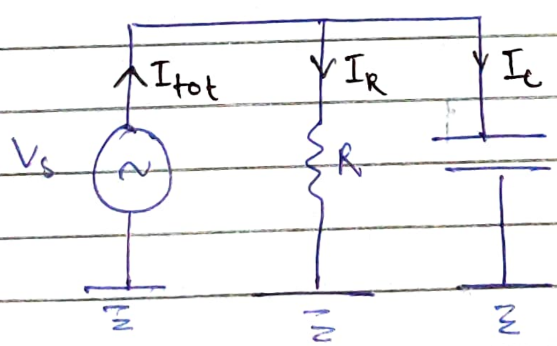


Comparison between Spice Simulations and Theory Calculations

We can see that the time domain graph of I_{tot} and total power is inverted. The reason behind this is explained below -

The directions of current ~~we~~ chosen for theory calcullation are given below,



On SPICE, direction of I_R and I_c is same but the direction of I_s is inverted.

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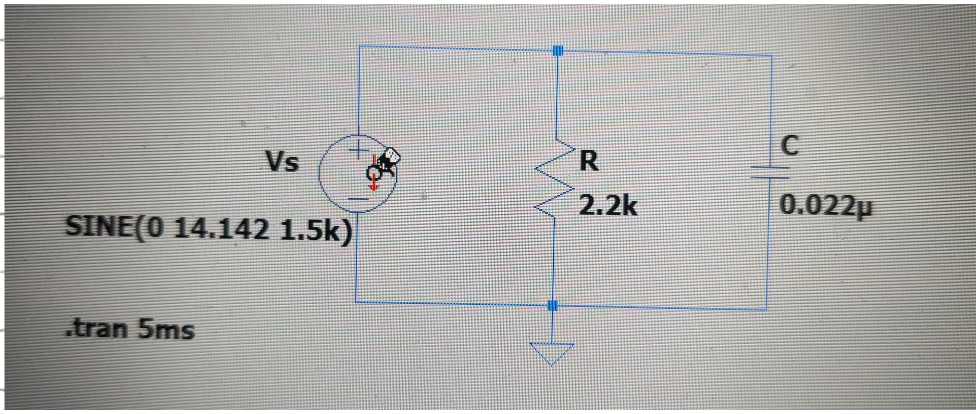


As you can see the arrow is pointing downwards. That is why, the total current and total power ~~time~~ domain graphs are inverted on SPICE.

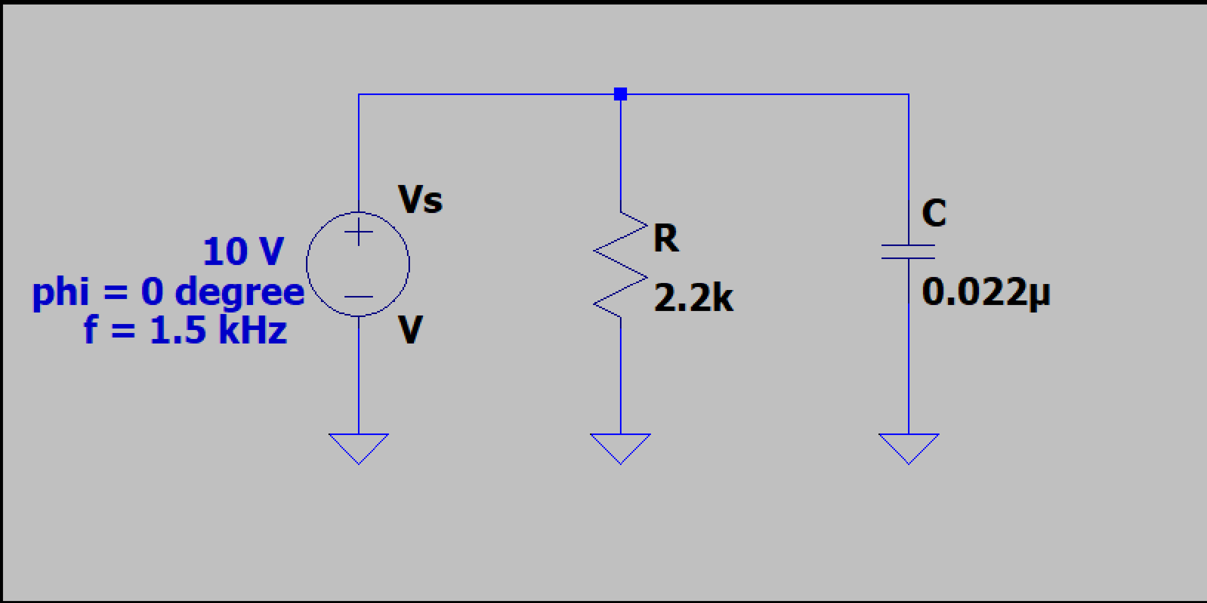
Now, the phase angle

Component	Angle
V_s	0°
I_C	90°
I_R	0°
I_{tot}	24.518°

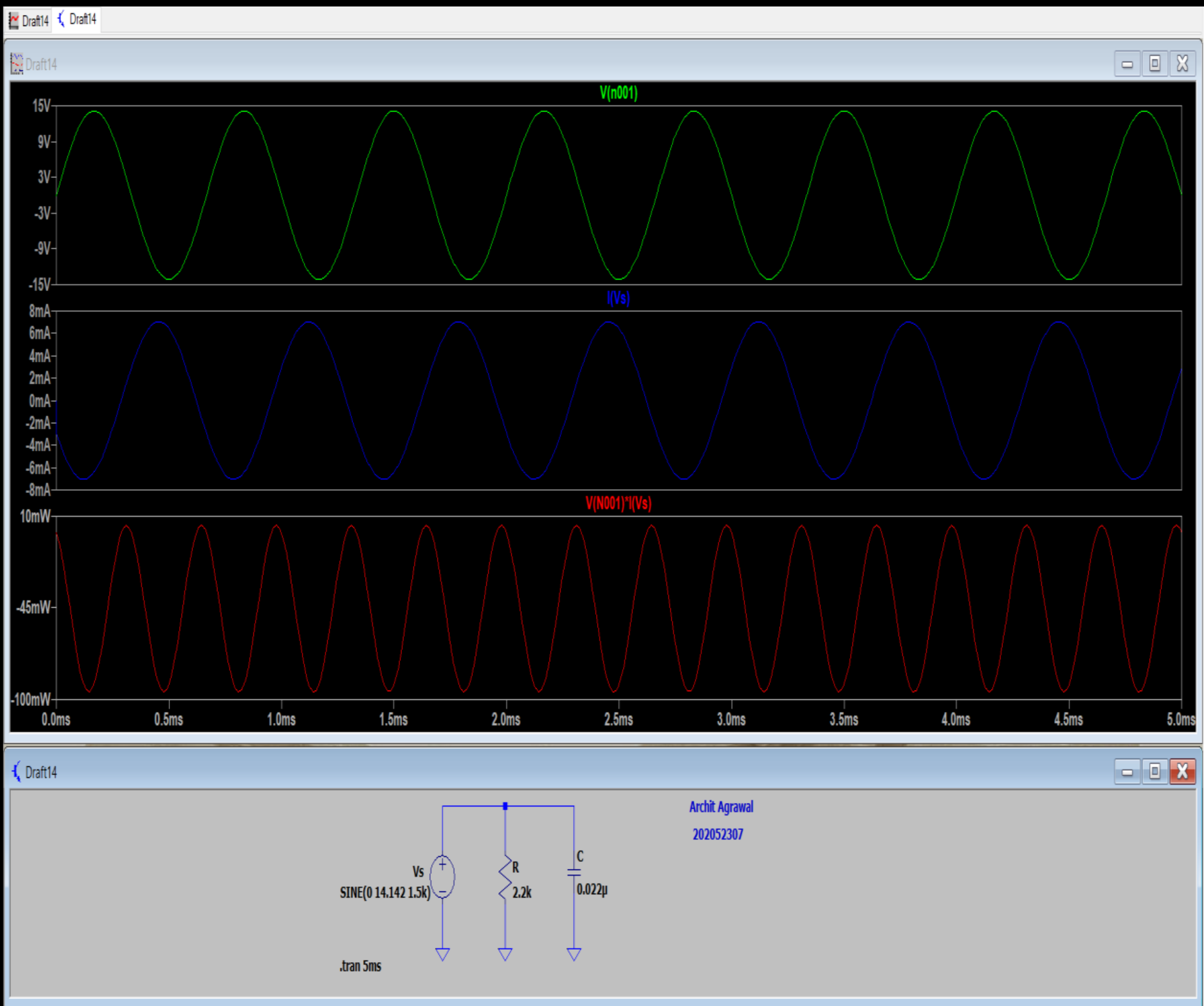
On SPICE, phase angle of I_{tot} is given to be -155.479°. This is because of the same reason mentioned above. Because of the reverse direction the phase changes by 180°. Clearly, $24.518^\circ - 180^\circ$ equals -155.482°.

EE160 : Experiment 2

Circuit

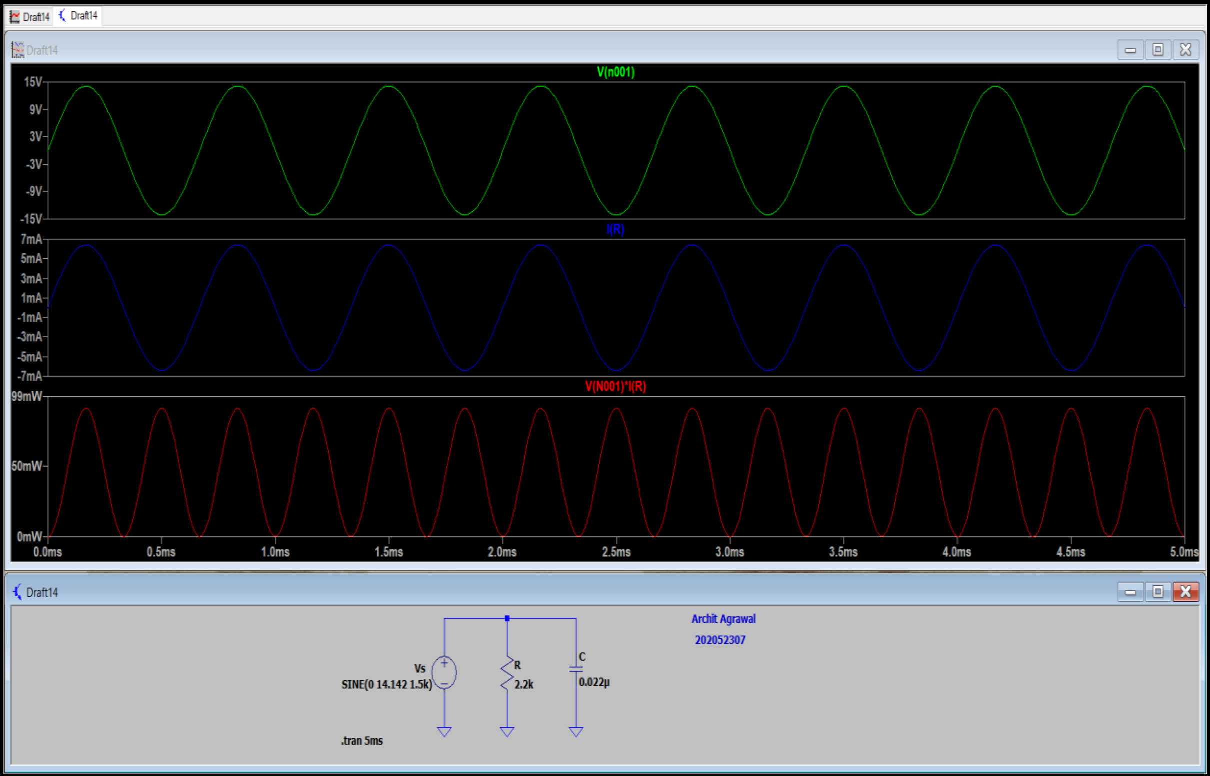


Source Voltage, Total Current and Total Power

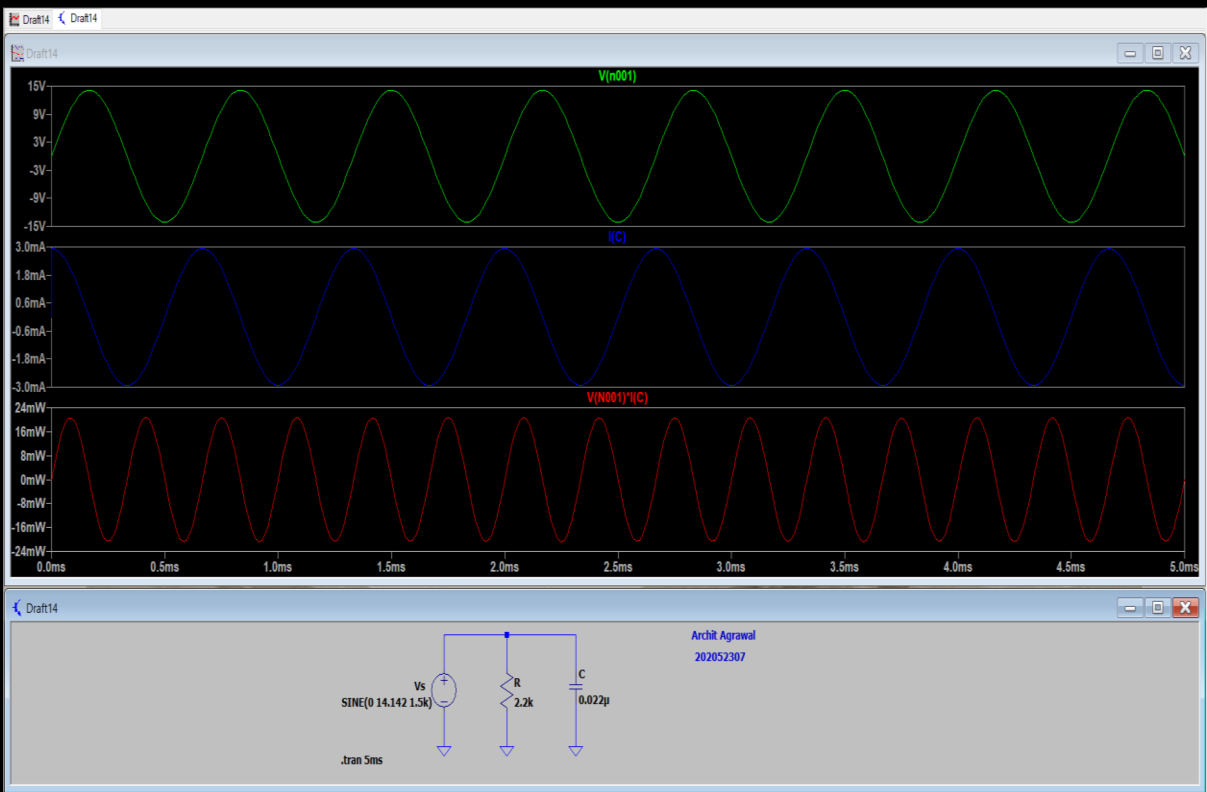


EE160 : Experiment 2

Voltage, current and Power across Resistor



Voltage, current and Power across Capacitor



EE160 : Experiment 2

AC Analysis

* C:\Users\Archit\Documents\LTspiceXVII\Draft14.asc

```
       --- AC Analysis ---

frequency:     1500           Hz
V(n001):       mag:          10 phase:          0°         voltage
I(C):          mag: 0.00207345 phase:         90°         device_current
I(R):          mag: 0.00454545 phase:          0°         device_current
I(Vs):         mag: 0.00499603 phase:   -155.479°         device_current
```

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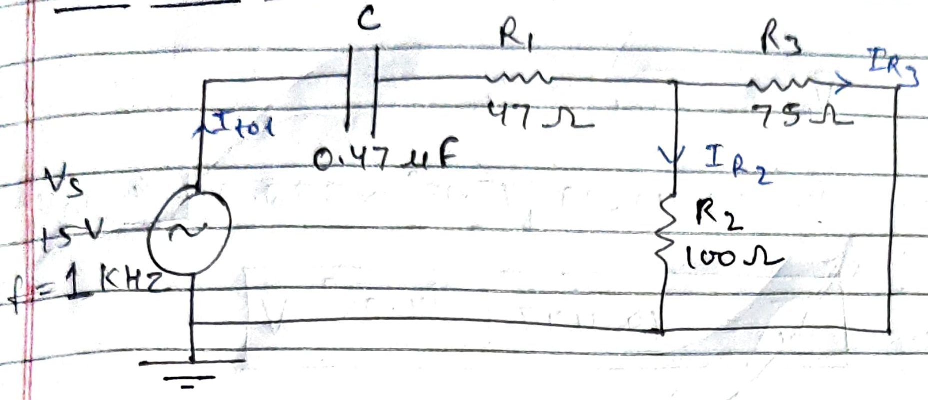
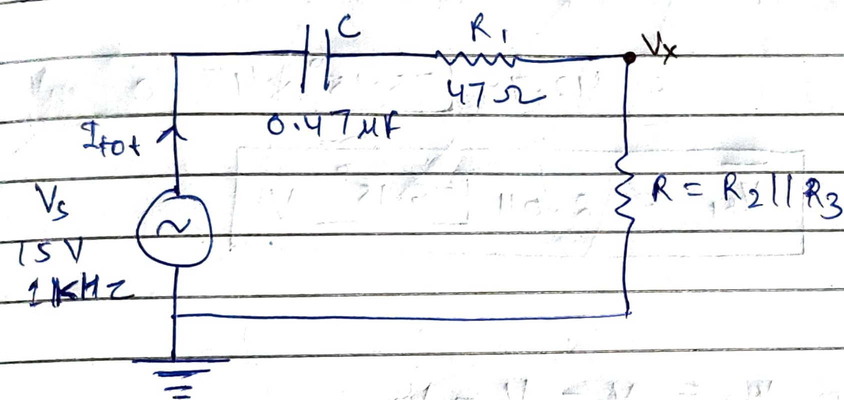
CIRCUIT 2



The circuit can be redrawn as



$$\therefore\ R = \frac{100 \times 75}{175} = 42.857\,\Omega$$

$$X_c = \frac{1}{\omega C} = \frac{1}{2\pi(1k)(0.47\mu)} = 338.8\,\Omega$$

$$\therefore\ Z = (47 + 42.857) - j(338.8)\ \Omega$$

$$\bar{Z} = 350.50 \angle -75.15^\circ\ \Omega$$

$$\therefore\ \bar{I}_{tot} = \frac{\bar{V}_s}{\bar{Z}} = \frac{15\angle 0^\circ}{350.50\angle -75.15^\circ}$$

$$\boxed{\begin{aligned}\bar{I}_{tot} &= 42.79 \angle 75.15^\circ\ mA \\ \bar{I}_{tot} &= 10.967 + j(41.361)\ mA\end{aligned}}$$

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$\therefore \quad \bar{I_c} = \bar{I_{R_1}} = \bar{I_{tot}}$

$\therefore \quad \bar{V_c} = \bar{I_{tot}} \times Z_c$

$\bar{V_c} = 42.79 \angle 75.15^\circ \times 338.8 \angle -90^\circ \text{ mV}$

$$\boxed{\bar{V_c} = 14.497 \angle -14.85^\circ \text{ V}}$$

and $\quad \bar{V_{R_1}} = \bar{I_{tot}} \times \bar{Z_{R_1}}$

$= 42.79 \angle 75.15^\circ \times 47 \angle 0^\circ \text{ mV}$

$$\boxed{\bar{V_{R_1}} = 2.011 \angle 75.15^\circ \text{ V}}$$

Now, $\quad V_x = V_s - V_c - V_{R_1}$

and, $\quad V_c = 14.013 - j(3.715) \text{ V}$
and, $\quad V_{R_1} = 0.515 + j(1.944) \text{ V}$

$\therefore V_x = 15 - (14.013 - j(3.715)) - (0.515 + j(1.944$

$V_x = 0.472 + j(1.771) \text{ V}$
$\bar{V_x} = 1.834 \angle 75.15^\circ \text{ V}$

Since, $\boxed{\bar{V_{R_2}} = \bar{V_{R_3}} = \bar{V_x} = 1.834 \angle 75.15^\circ \text{ V}}$

$\therefore \quad \bar{I_{R_2}} = \dfrac{\bar{V_{R_2}}}{\bar{Z_{R_2}}} = \dfrac{1.834 \angle 75.15^\circ}{100 \angle 0^\circ} \text{ A}$

$$\boxed{\bar{I_{R_2}} = 18.34 \angle 75.15^\circ \text{ mA}}$$

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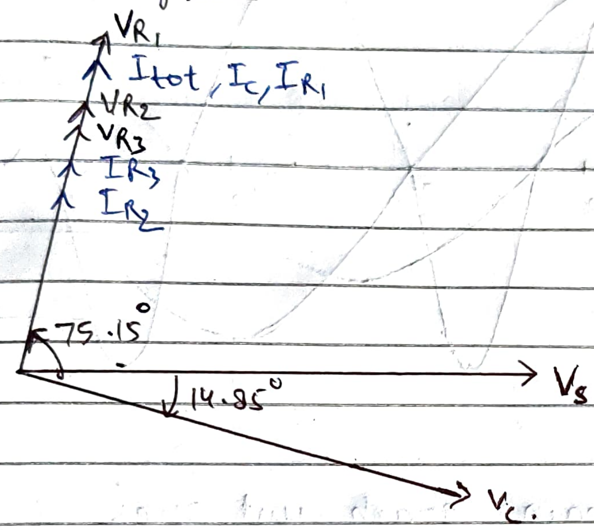
$$\overline{I_{R_3}} = \frac{\overline{V_{R3}}}{\overline{Z_{R_3}}} = \frac{1.834 \angle 75.15^\circ}{75 \angle 0^\circ} \text{ A}$$

$$\boxed{\overline{I_{R_3}} = 24.453 \angle 75.15^\circ \text{ mA}}$$

Phasor Diagram



Time Domain

Given $\overline{V_s} = 15 \angle 0^\circ$ V

$\therefore V_{rms} = 15$ V

$V_m = 15\sqrt{2}$ V

In time domain, we write peak value

$$V_s = 15\sqrt{2}\sin(6280t + 0^\circ)$$

$$V_c = 14.447\sqrt{2}\sin(6280t + 75.15^\circ - 90^\circ) \text{ V}$$

$$V_c = 14.447\sqrt{2}\sin(6280t - 14.85^\circ) \text{ V}$$

$$V_{R_1} = 2.011\sqrt{2}\sin(6280t + 75.15^\circ) \text{ V}$$

$$V_{R_2} = V_{R_3} = 1.834\sqrt{2}\sin(6280t + 75.15^\circ) \text{ V}$$

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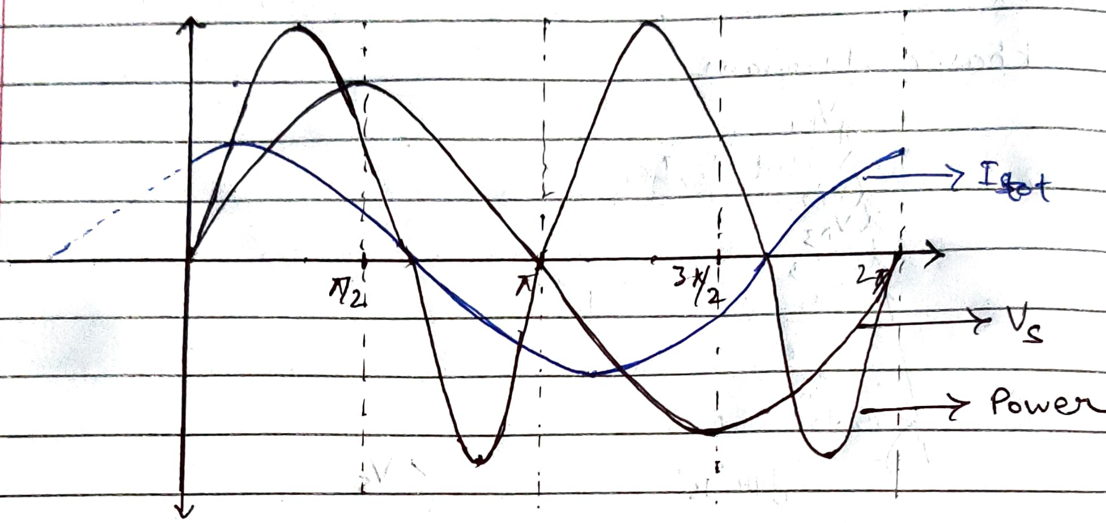
$$I_{tot} = I_c = I_{R_1} = 42.79\sqrt{2}\sin(6280t + 75.15^\circ)\text{ mA}$$

$$I_{R_2} = 18.34\sqrt{2}\sin(6280t + 75.15^\circ)\text{ mA}$$

$$I_{R_3} = 24.453\sqrt{2}\sin(6280t + 75.15^\circ)\text{ mA}$$



The time domain graph just gives an idea of phase of V_s and I_{tot} and the magnitude of I_{tot}, V_s and power are not implied by it.

Comparison between Spice Simulations and Theory Calculations

We can see the time domain graph of I_{tot} and total power is inverted. The reason behind this is explained below

The direction of currents chosen for theory calculations are drawn in the circuit

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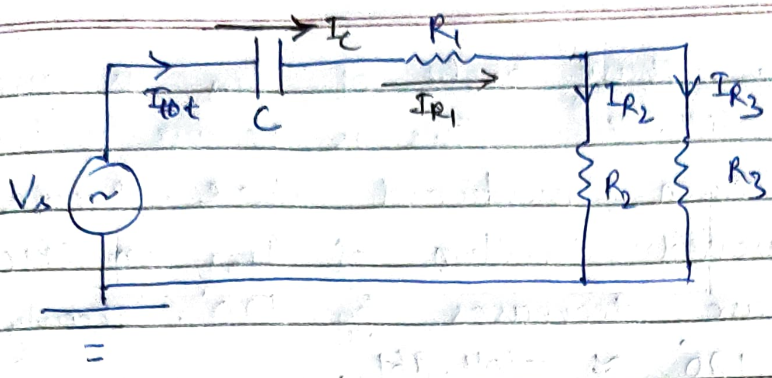
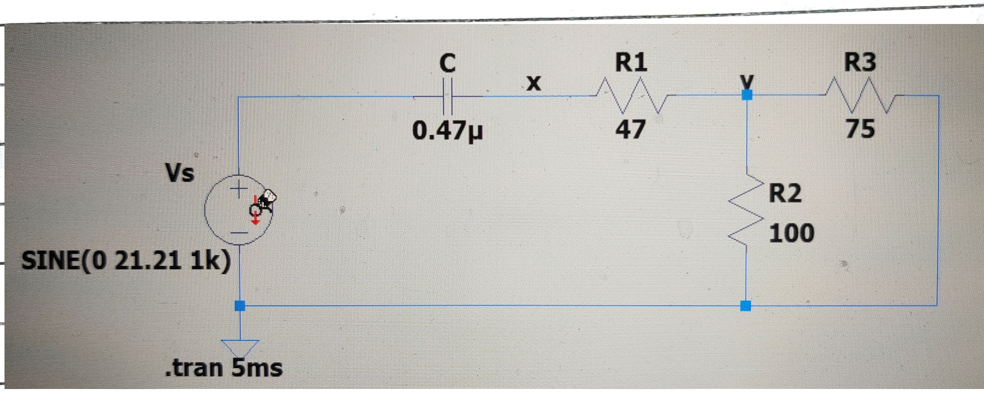


On SPICE, the direction of currents is same as this except for the direction of ~~tot~~ I_{tot}.



As you can see the arrow is pointing downwards. That is why, the total current and total power time domain graphs are inverted on SPICE.

Now, the phase angles

Component	Angle
V_s	0°
V_c	-14.85°
V_{R_1}, V_{R_2}, V_{R_3}	75.15°
I_{tot}, I_c, I_{R_1}	75.15°
I_{R_2}, I_{R_3}	75.15°

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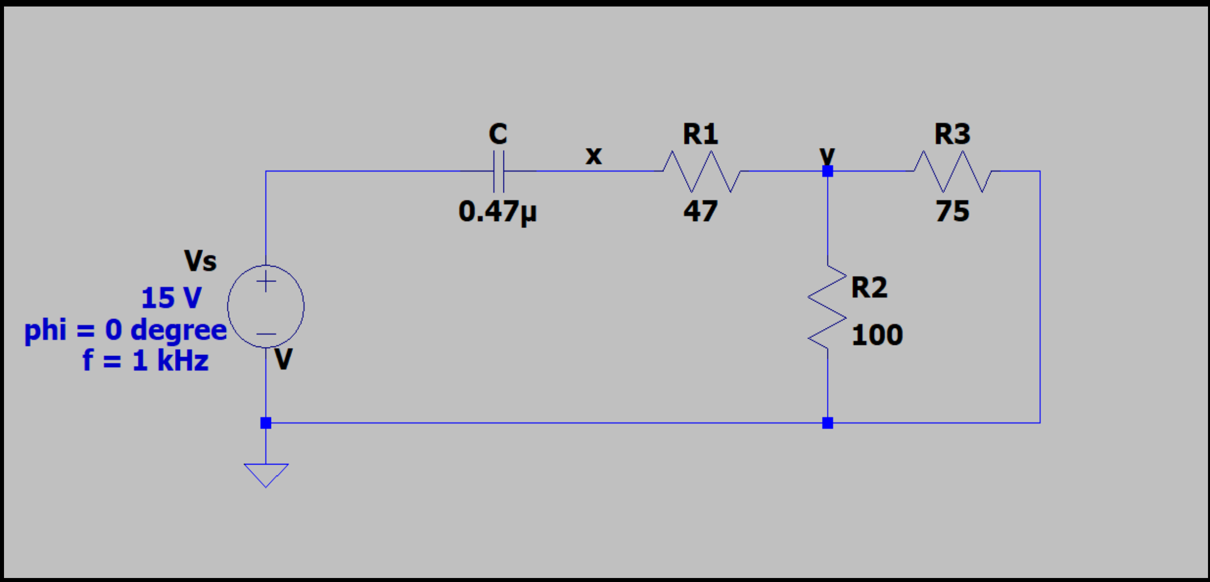
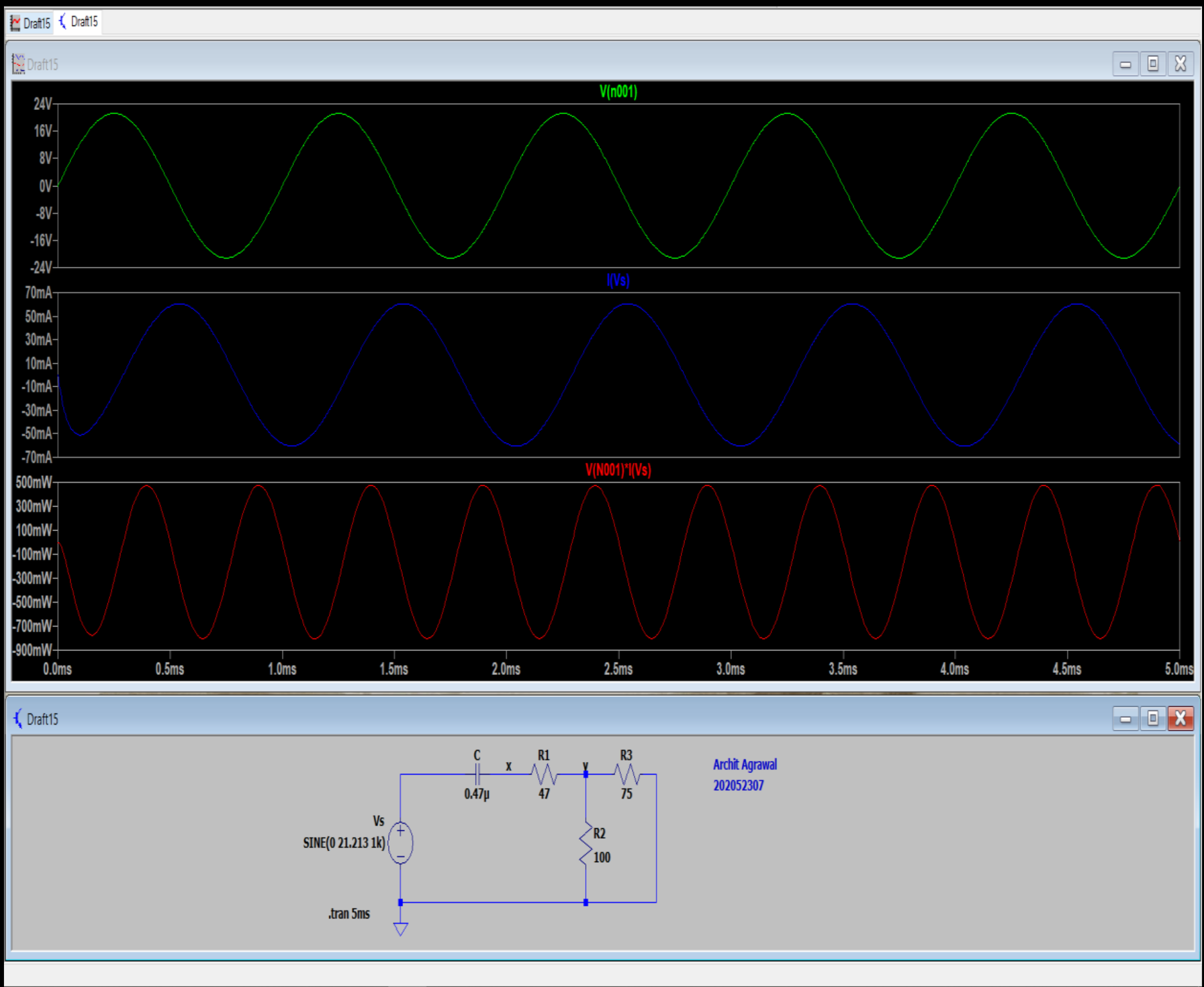
On SPICE, phase angle of I_{tot} is given to be -104.861°. This is because of the same reason mentioned above. Because of the reversed direction of I_{tot} on SPICE, the phase decreases by 180°. Clearly, $75.15^\circ - 180^\circ \approx -104.861^\circ$.

EE160 : Experiment 2

Circuit

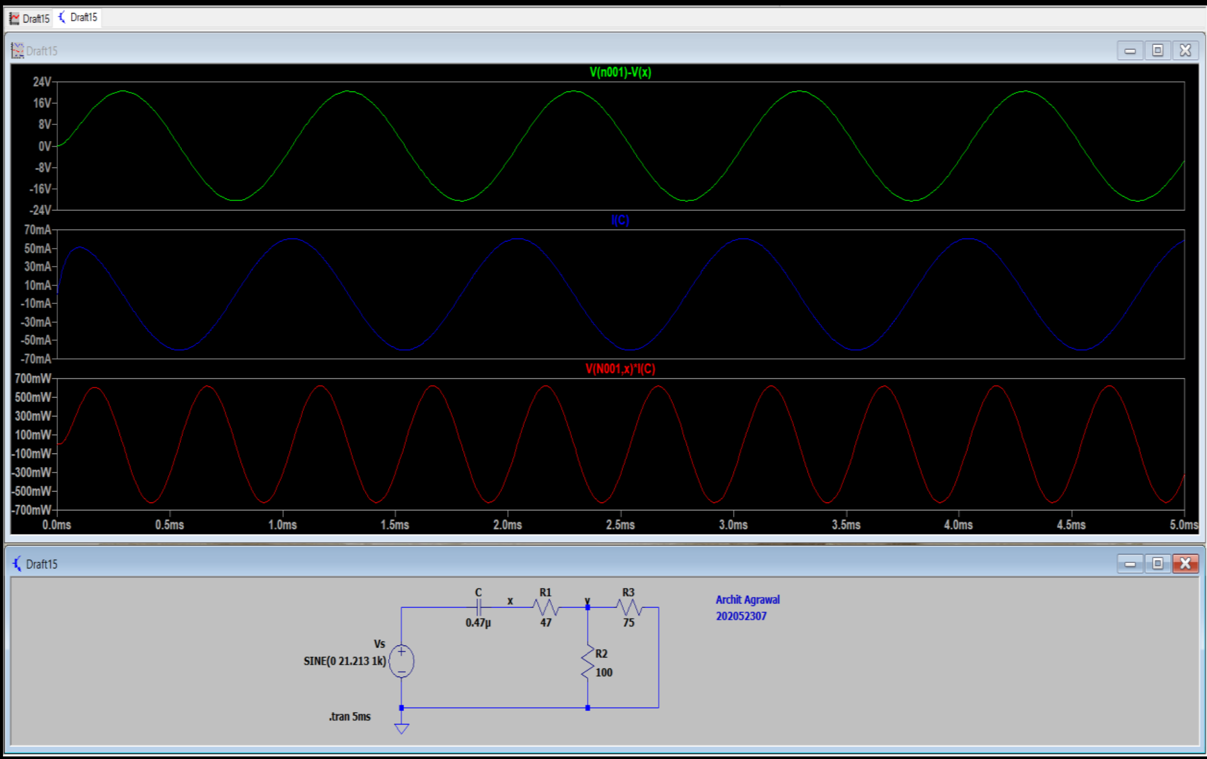


Source Voltage, Total Current and Total Power

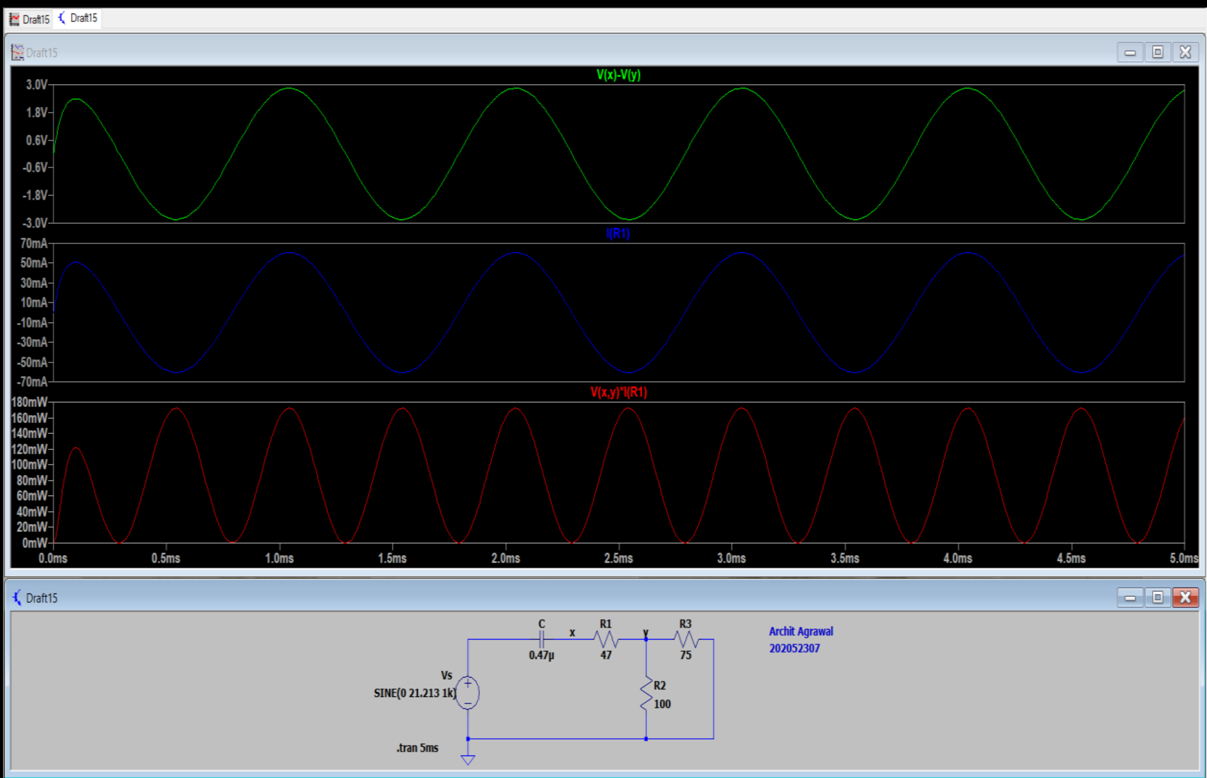


EE160 : Experiment 2

Voltage, current and Power across Capacitor

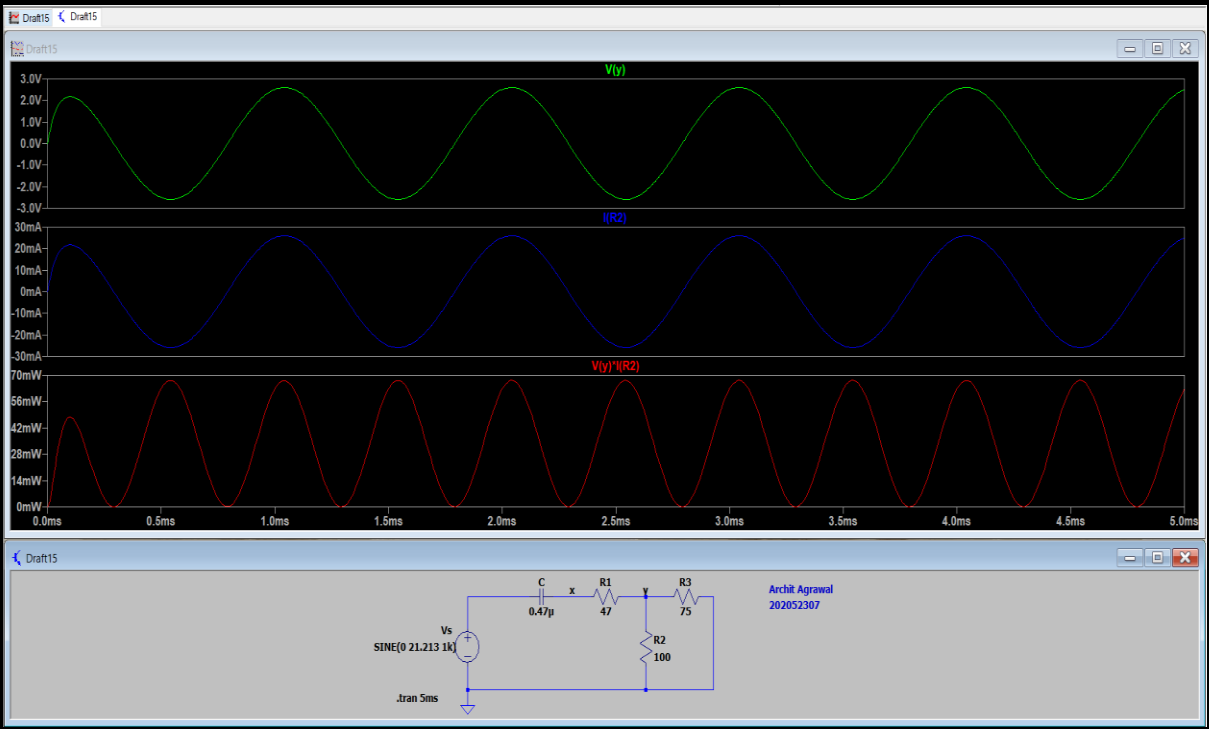


Voltage, current and Power across Resistor R_1

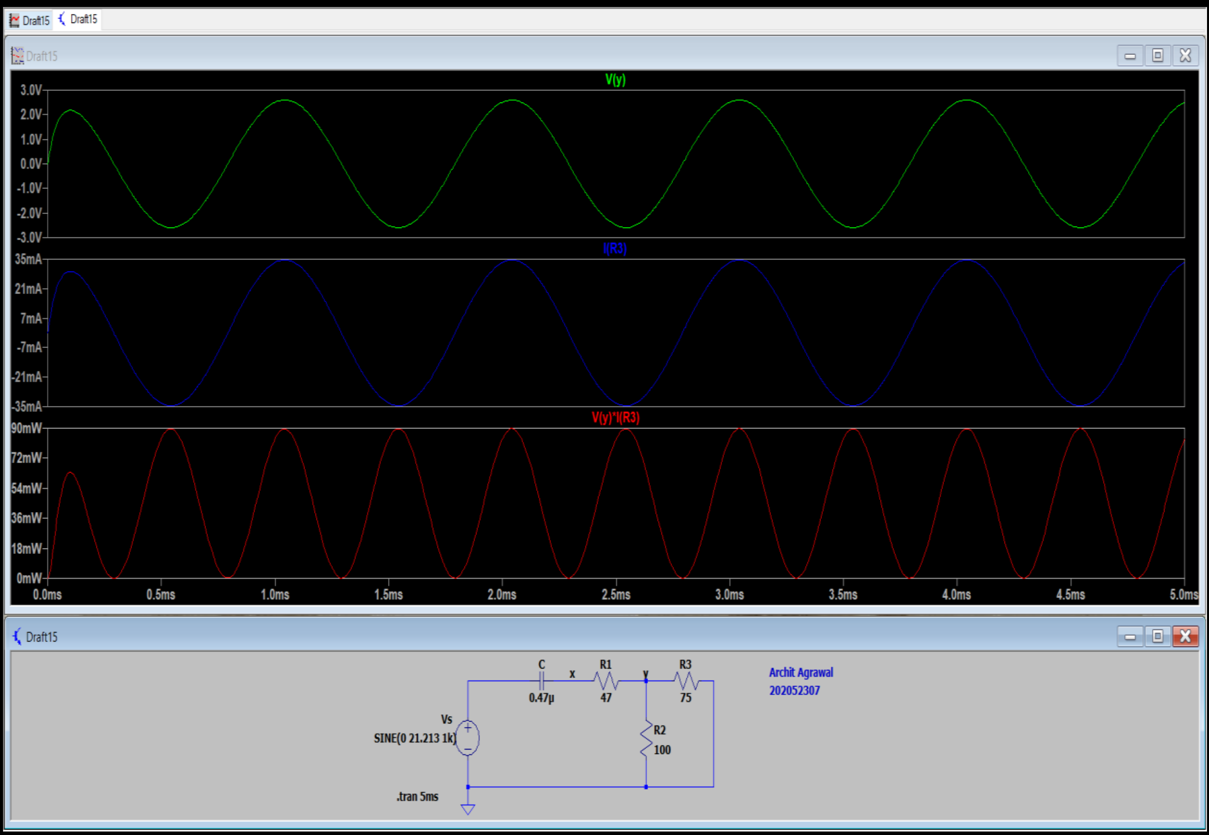


EE160 : Experiment 2

Voltage, current and Power across Resistor R_2



Voltage, current and Power across Resistor R_3



EE160 : Experiment 2

AC Analysis

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```
       --- AC Analysis ---

frequency:     1000           Hz
V(n001):       mag:         15 phase: 1.6963e-015°        voltage
V(x):          mag:    3.84721 phase:     75.1387°        voltage
V(y):          mag:    1.83492 phase:     75.1387°        voltage
I(C):          mag:  0.0428147 phase:     75.1387°        device_current
I(R3):         mag:  0.0244656 phase:     75.1387°        device_current
I(R1):         mag:  0.0428147 phase:     75.1387°        device_current
I(R2):         mag:  0.0183492 phase:     75.1387°        device_current
I(Vs):         mag:  0.0428147 phase:    -104.861°        device_current
```

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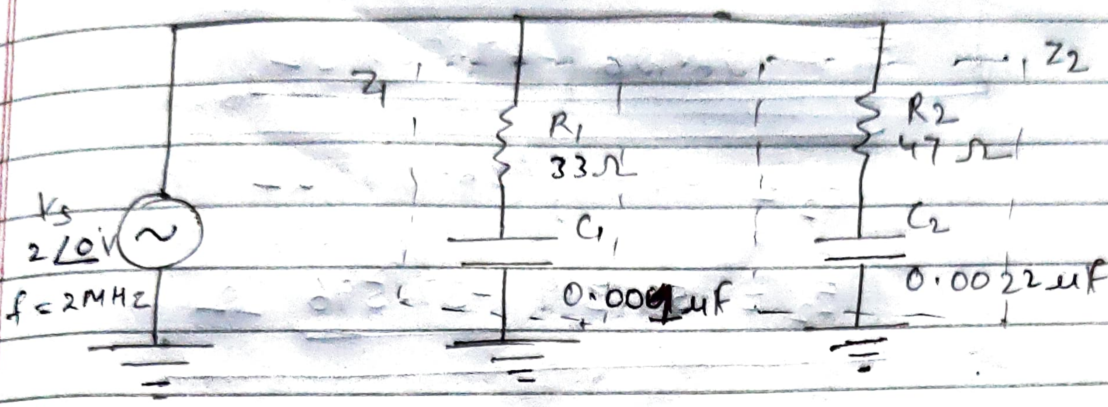
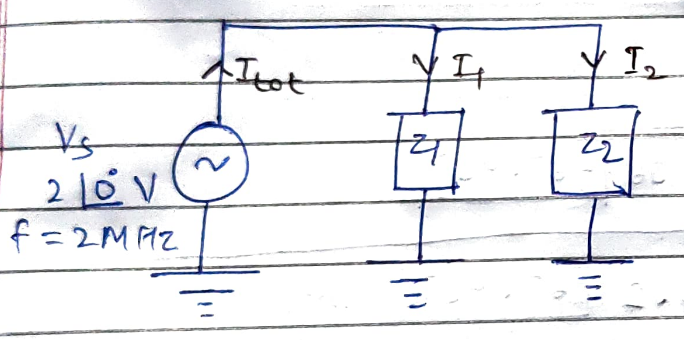
CIRCUIT 3 -:



the circuit can be redrawn as



where Z_1 and Z_2 are net impedances of R_1, C_1 and R_2, C_2 respectively.

$$X_{C_1} = \frac{1}{2\pi f (C_1)} = \frac{1}{2 \times 3.14 \times 2M \times 0.001\,\mu}$$

$$X_{C_1} = 79.618\ \Omega$$

and $X_{C_2} = \frac{1}{2\pi f (C_2)} = \frac{1}{2 \times 3.14 \times 2M \times 0.0022\,\mu}$

$$X_{C_2} = 36.19\ \Omega$$

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$$\boxed{\begin{aligned} \therefore Z_1 &= 33 - j(79.618)\ \Omega \\ \bar{Z}_1 &= 86.186\,\angle -67.487^\circ\ \Omega \end{aligned}}$$

and
$$\boxed{\begin{aligned} Z_2 &= 47 - j(36.19)\ \Omega \\ \bar{Z}_2 &= 59.319\,\angle -37.596\ \Omega \end{aligned}}$$

$$\therefore \bar{I}_1 = \frac{\bar{V}_s}{\bar{Z}_1}$$

$$= \frac{2\,\angle 0^\circ}{86.186\,\angle -67.487^\circ}\ A$$

$$\boxed{\begin{aligned} \bar{I}_1 &= 23.2\,\angle 67.487^\circ\ mA \\ I_1 &= 8.883 + j(21.432)\ mA \end{aligned}}$$

and
$$\bar{I}_2 = \frac{\bar{V}_s}{\bar{Z}_2}$$

$$= \frac{2\,\angle 0^\circ}{59.319\,\angle -37.596^\circ}\ A$$

$$\boxed{\begin{aligned} \bar{I}_2 &= 33.72\,\angle 37.596^\circ\ mA \\ I_2 &= 26.72 + j(20.57)\ mA \end{aligned}}$$

From KCL,
$$I_{tot} = I_1 + I_2$$

$$I_{tot} = (8.883 + 26.72) + j(21.432 + 20.57)\ mA$$

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$I_{tot} = 35.603 + j(42.002)$ mA

$$\boxed{\overline{I_{tot}} = 55.061 \angle 49.713^\circ \text{ mA}}$$

$\because \overline{I_{R_1}} = \overline{I_{C_1}} = \overline{I_1} = 23.2 \angle 67.487^\circ$ mA

$\therefore \overline{V_{R_1}} = \overline{I_{R_1}} \times \overline{Z_{R_1}}$

$= 23.2 \angle 67.487 \times 33 \angle 0^\circ$ mV

$$\boxed{V_{R_1} = 0.766 \angle 67.487^\circ \text{ V}}$$

and, $\overline{V_{C_1}} = \overline{I_{C_1}} \times \overline{Z_{C_1}}$

$= 23.2 \angle 67.487^\circ \times 79.618 \angle -90^\circ$ mV

$$\boxed{\overline{V_{C_1}} = 1.847 \angle -22.513^\circ \text{ V}}$$

$\because \overline{I_{R_2}} = \overline{I_{C_2}} = \overline{I_2} = 33.72 \angle 37.596^\circ$ mA

$\therefore \overline{V_{R_2}} = \overline{I_{R_2}} \times \overline{Z_{R_2}}$

$= 33.72 \angle 37.596^\circ \times 47 \angle 0^\circ$ mV

$$\boxed{V_{R_2} = 1.585 \angle 37.596^\circ \text{ V}}$$

and, $\overline{V_{C_2}} = \overline{I_{C_2}} \times \overline{Z_{C_2}}$

$= 33.72 \angle 37.596^\circ \times 36.19 \angle -90^\circ$ mV

$$\boxed{\overline{V_{C_2}} = 1.22 \angle -52.404^\circ \text{ V}}$$

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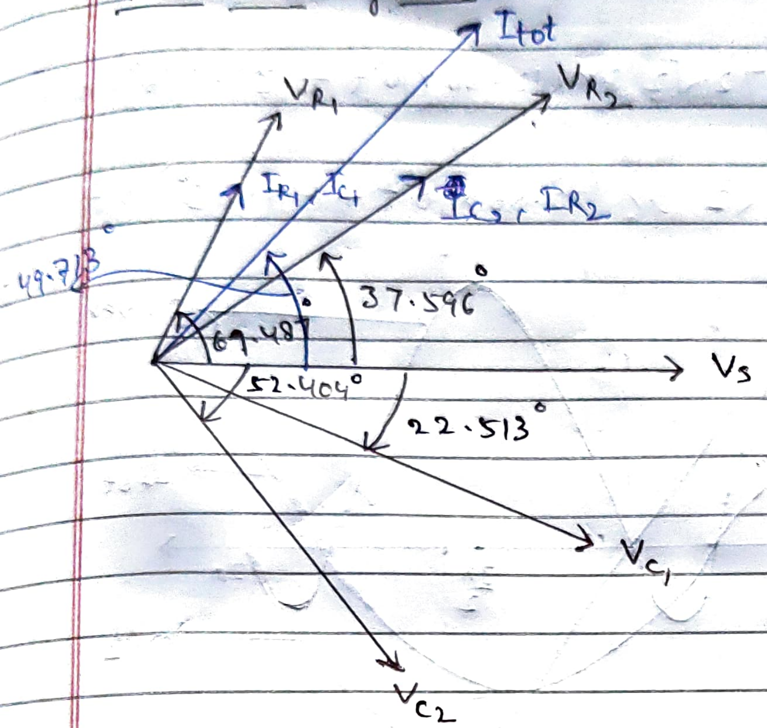
Phasor Diagram



Time Domain

Given $V_s = 2\angle 0^\circ$ V

$\therefore V_{rms} = 2$ V

$\therefore V_m = 2\sqrt{2}$ V

In time domain, we write peak values,

$\therefore V_s = 2\sqrt{2}\sin(12.56\times10^6 t + 0^\circ)$ V

$V_{R_1} = 0.766\sqrt{2}\sin(12.56\times10^6 t + 67.487^\circ)$ V

$V_{C_1} = 1.847\sqrt{2}\sin(12.56\times10^6 t - 22.513^\circ)$ V

$V_{R_2} = 1.585\sqrt{2}\sin(12.56\times10^6 t + 37.596^\circ)$ V

$V_{C_2} = 1.22\sqrt{2}\sin(12.56\times10^6 t - 52.404^\circ)$ V

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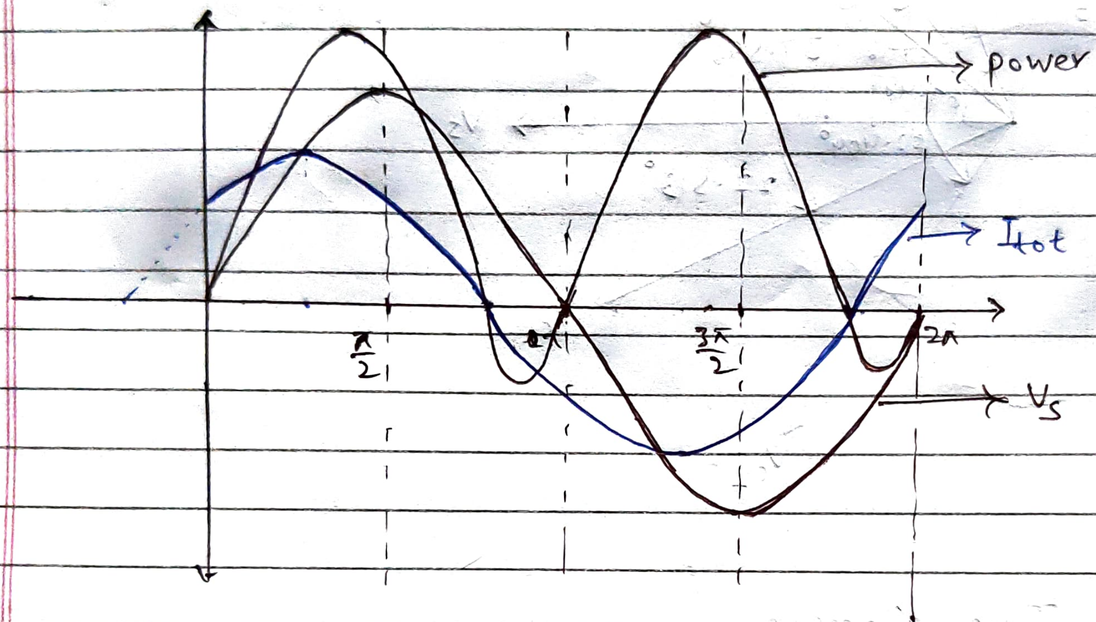
$$I_{R_1} = I_{C_1} = 23.2\sqrt{2}\ \sin\left(12.56\times10^{6}t + 67.487^{\circ}\right)\ mA$$

$$I_{R_2} = I_{C_2} = 33.72\sqrt{2}\ \sin\left(12.56\times10^{6}t + 37.596^{\circ}\right)\ mA$$

$$I_{tot} = 55.061\sqrt{2}\ \sin\left(12.56\times10^{6}t + 49.713^{\circ}\right)\ mA$$



The time domain graph just gives an idea of phase of V_s and I_{tot} and the magnitude of I_{tot}, V_s and power is not implied by it.

Comparison between SPICE Simulations and Theory Calculations

We can see the time domain graph of I_{tot} and total power are inverted on SPICE. The reason behind this is explained below -

The direction chosen for theory calculations are given in the circuit

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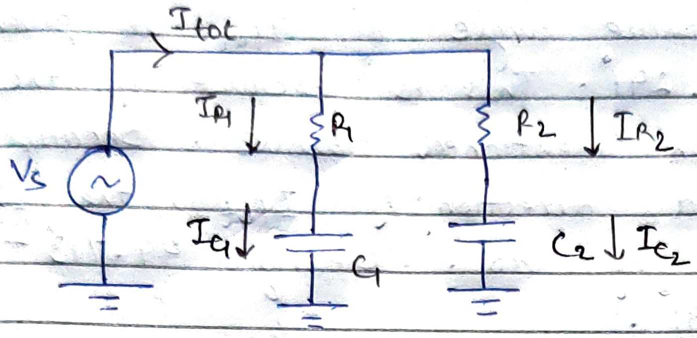
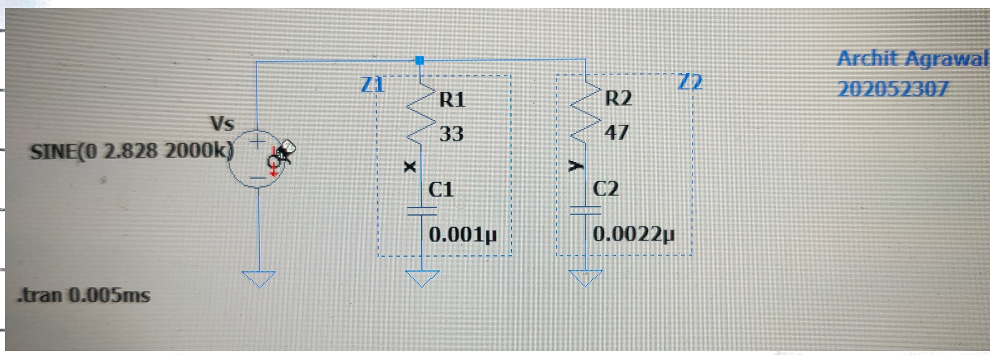


On SPICE, the direction of currents are similar to this except for I_{tot}.



As you can see the arrow is pointing downwards. That is why, the total power and total current time domain graphs are inverted on SPICE.

Now, the phase angles

Component	Angle
V_s	0°
V_{R_1}	67.487°
V_{R_2}	37.596°
V_{C_1}	-22.513°
V_{C_2}	-52.404°
I_{tot}	49.713°
I_{R_1}, I_{C_1}	67.487°
I_{R_2}, I_{C_2}	37.596°

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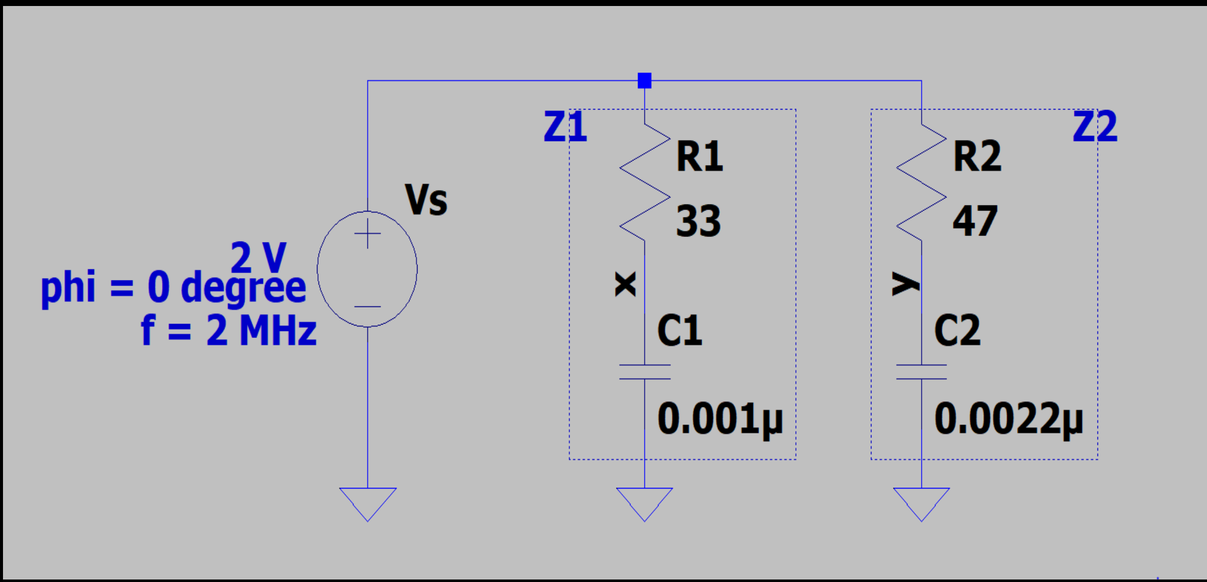
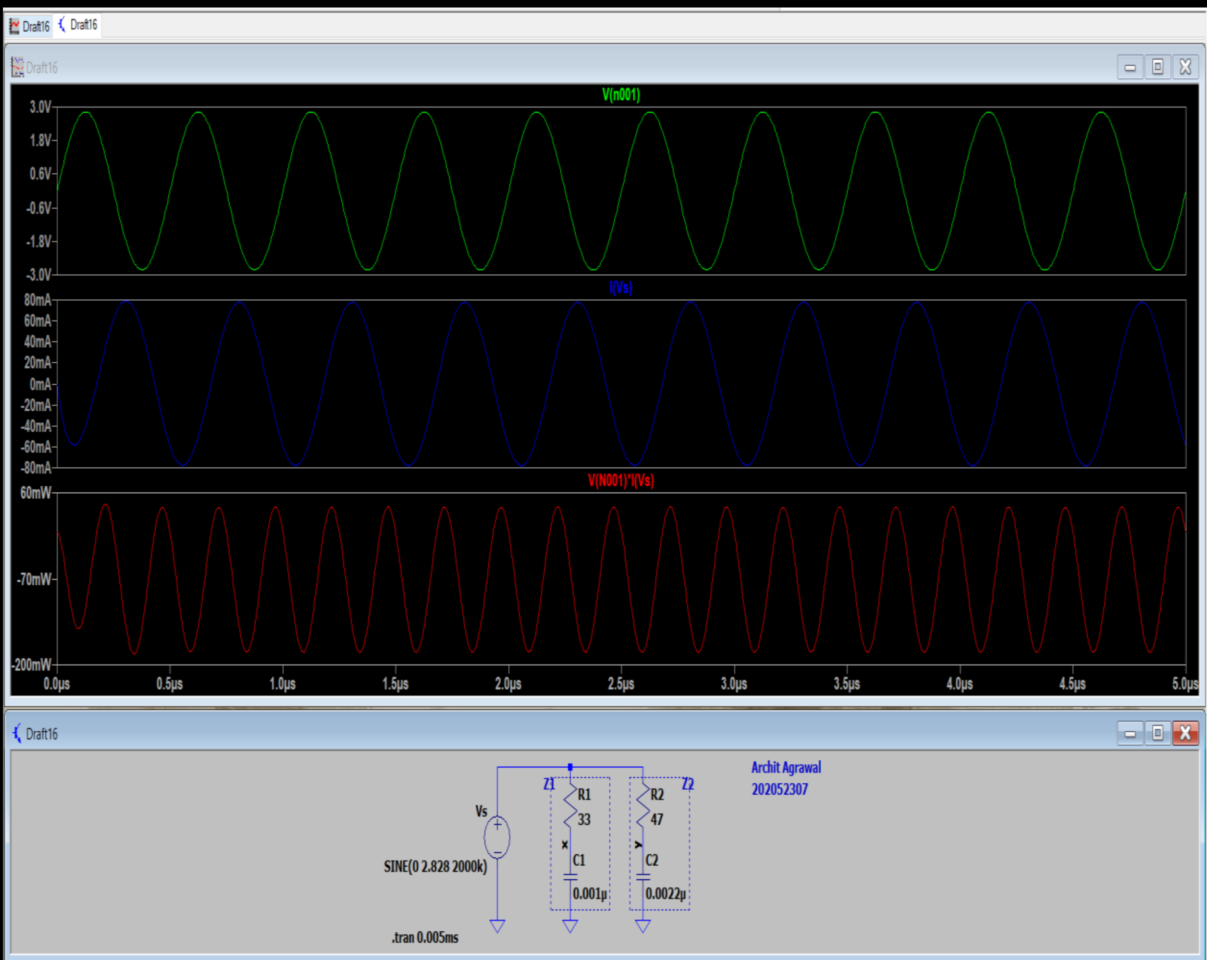
On SPICE, phase angle of I_{tot} is given to be -130.291°. This is because of the same reason mentioned above. Because of the reversed direction of I_{tot}, the phase decreases by 180°. Clearly $49.713^\circ - 180^\circ \approx 130.291^\circ$.

EE160 : Experiment 2

Circuit

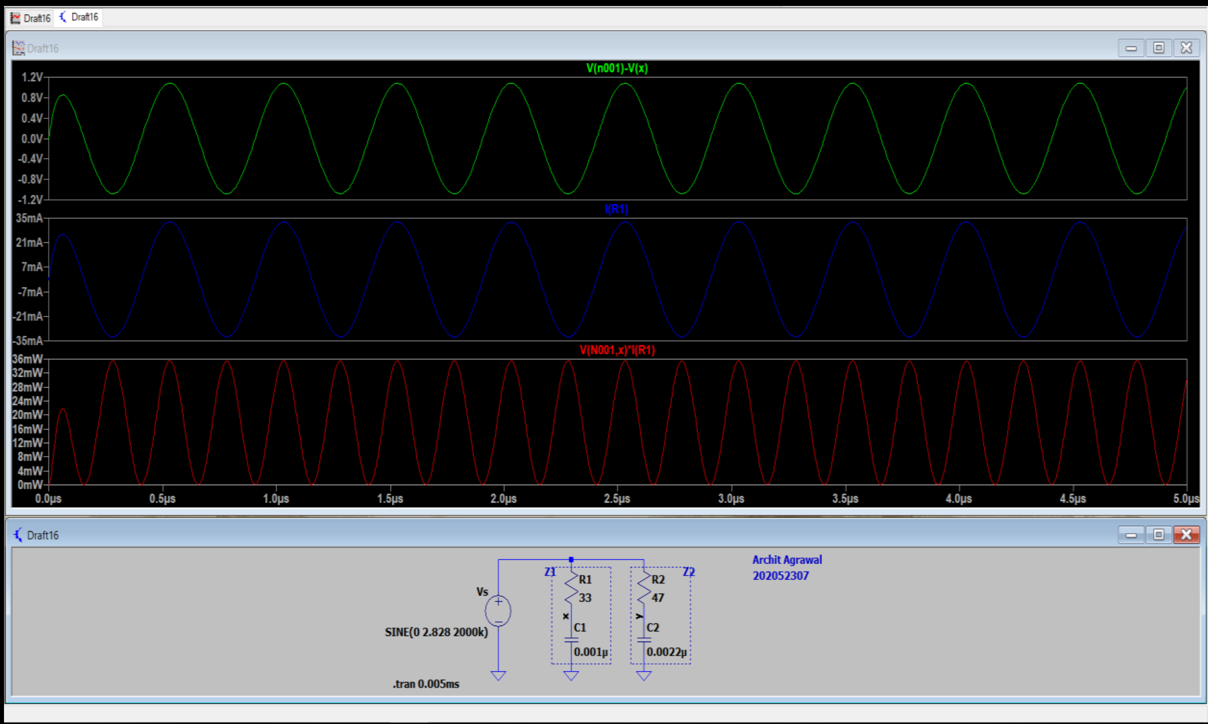


Source Voltage, Total Current and Total Power

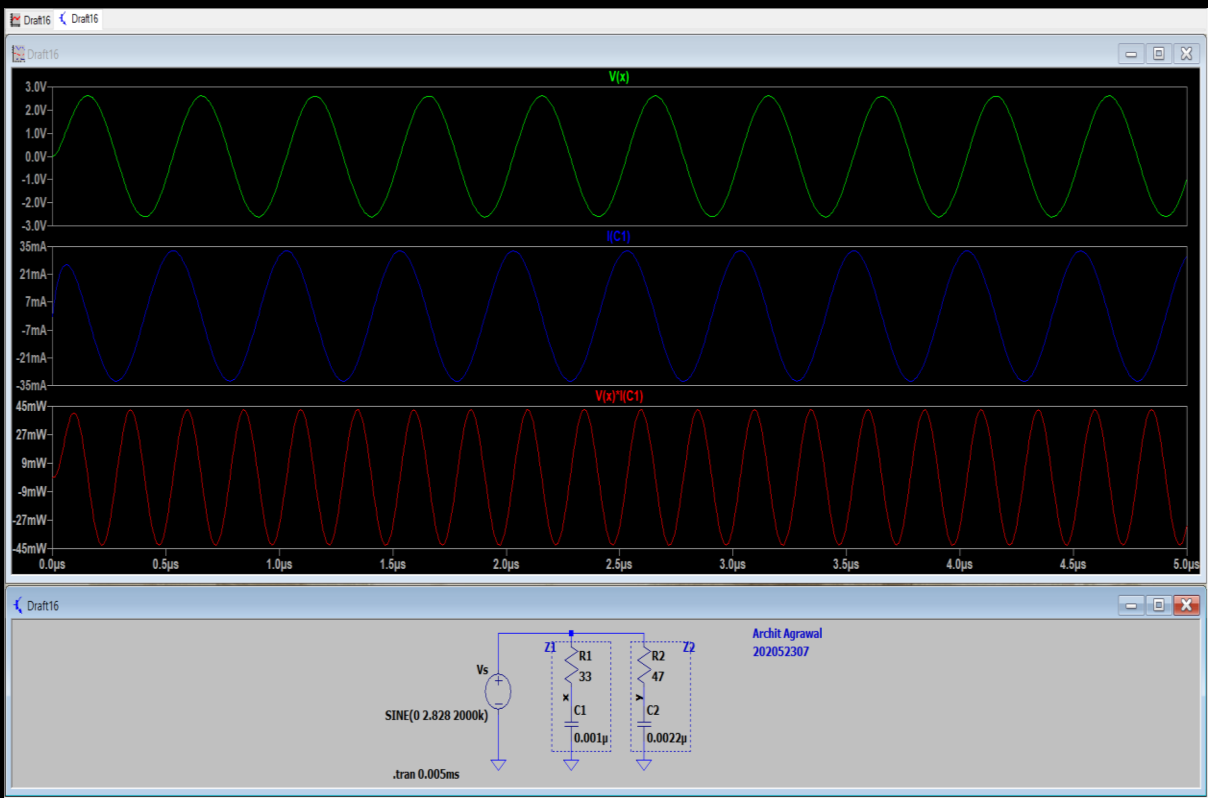


EE160 : Experiment 2

Voltage, current and Power across Resistor R_1

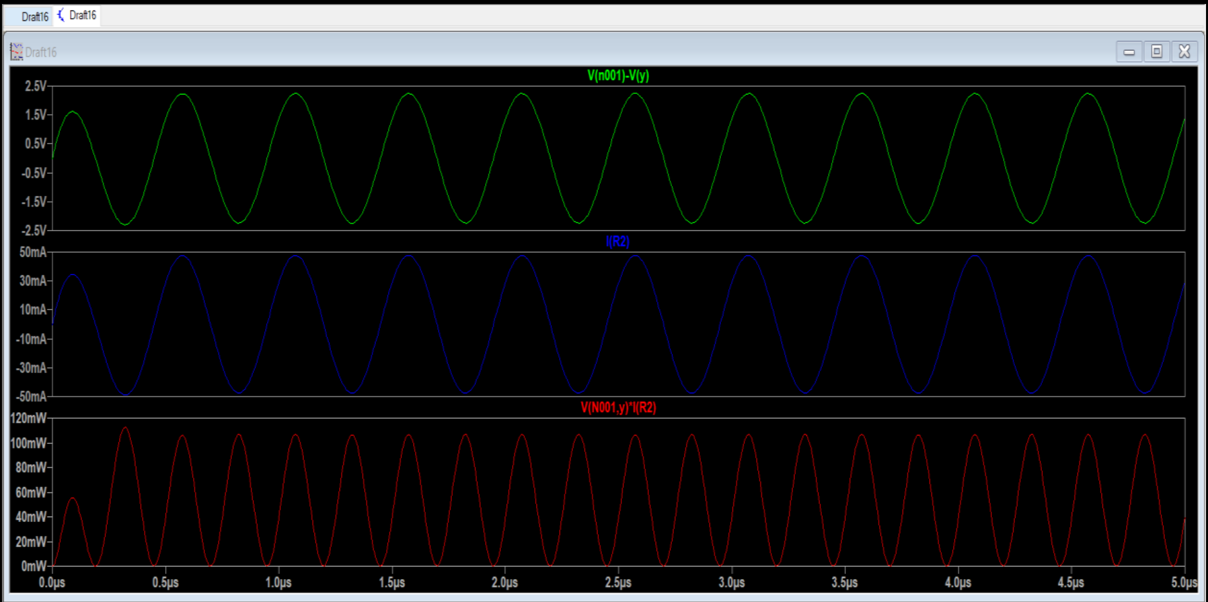


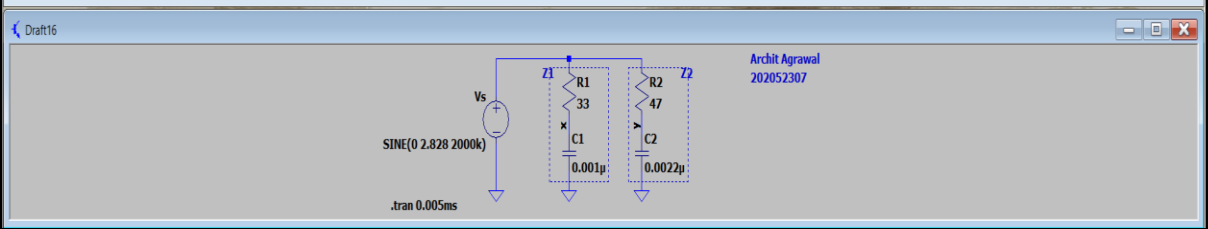
Voltage, current and Power across Capacitor C_1



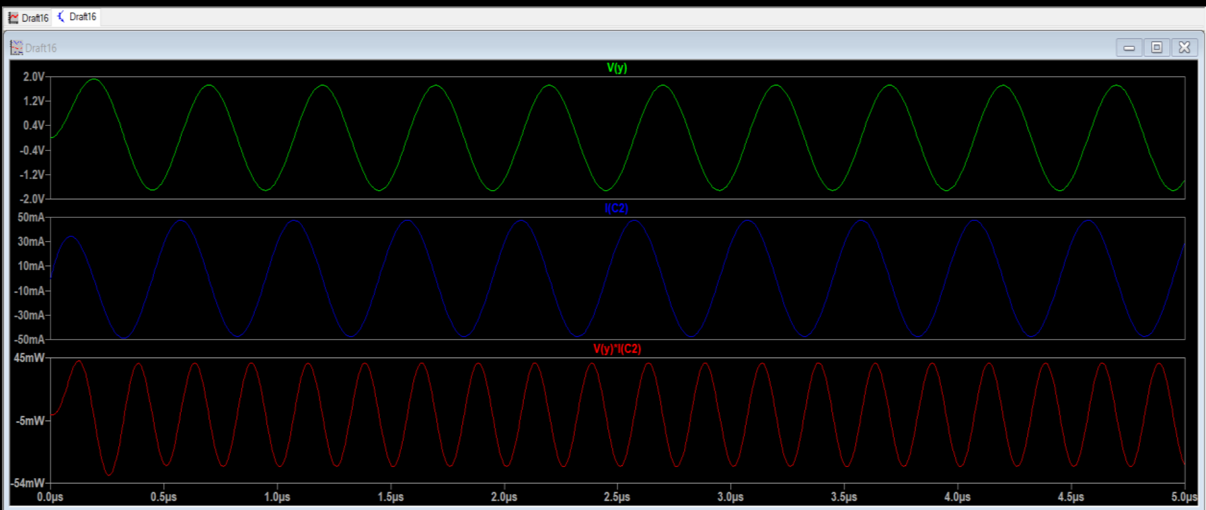
EE160 : Experiment 2

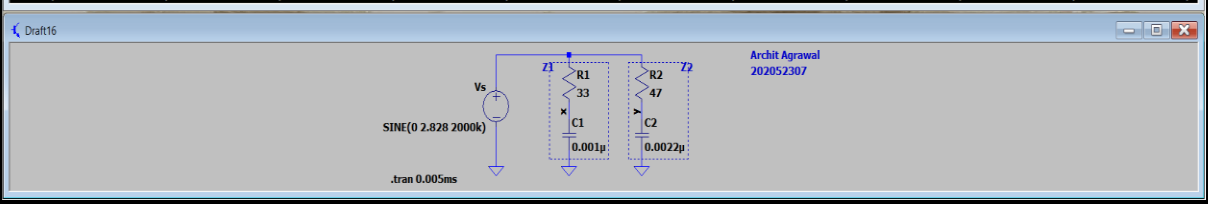
Voltage, current and Power across Resistor R_2





Voltage, current and Power across Capacitor C_2





EE160 : Experiment 2

AC Analysis

* C:\Users\Archit\Documents\LTspiceXVII\Draft16.asc

```
       --- AC Analysis ---

frequency:      2e+006          Hz
V(x):           mag:     1.84745 phase:    -22.5233°         voltage
V(y):           mag:      1.2198 phase:    -52.4178°         voltage
V(n001):        mag:           2 phase:           0°         voltage
I(C2):          mag:   0.0337225 phase:     37.5822°         device_current
I(C1):          mag:   0.0232157 phase:     67.4767°         device_current
I(R2):          mag:   0.0337225 phase:     37.5822°         device_current
I(R1):          mag:   0.0232157 phase:     67.4767°         device_current
I(Vs):          mag:   0.0550784 phase:    -130.291°         device_current
```

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Observations and Conclusions :-

Performing the experiment, following conclusions can be drawn

(i) The current through a resistor is in phase with the voltage across it.

(ii) the current through a capacitor leads the voltage across it by 90°.

(iii) A resistor is a power-dissipating device while a capacitor only stores and releases energy in an AC circuit.